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TRANSPORTATION-ENERGY CONSERVATION PLAN FOR THE BOSTON REGION: ANALYSIS OF POTENTIAL ACTIONS

MAY 1984

This document was prepared by **CENTRAL TRANSPORTATION PLANNING STAFF**, an interagency transportation planning staff created and directed by the Metropolitan Planning Organization, consisting of the member agencies.

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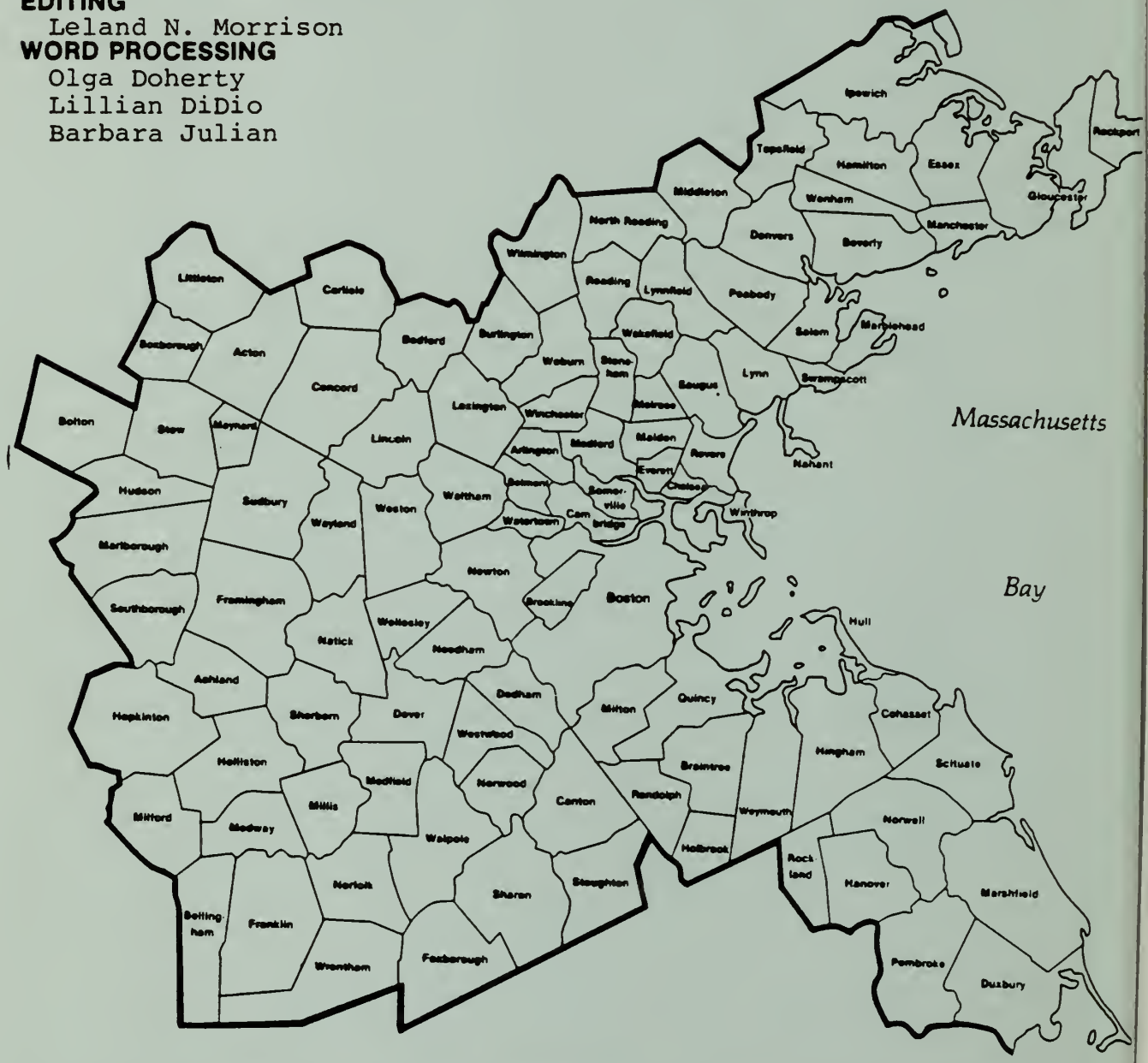

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TABLE OF CONTENTS

List of Figures and Tables v

1.0 Introduction: Study Objectives and Existing Conditions 1

2.0 Preferential Treatment of High-Occupancy Vehicles 9

BACKGROUND: TYPES OF ACTIONS 9

POTENTIAL APPLICATIONS IN THE BOSTON AREA 16

2.1 Extension of I-93 Preferential Lane 17

2.2 Southeast Expressway - Contra-flow Bus Lane and Priority Ramp-Bypass 20

2.3 Route 3 Exclusive HOV Lane 27

2.4 Route 1A/McClellan Highway: Reserved HOV Lane 31

2.5 Massachusetts Turnpike: Reserved HOV Lane 35

2.6 Priority Signal Treatments 37

3.0 Measures to Improve Total Vehicle Flow 43

BACKGROUND: TYPES OF ACTIONS 43

POTENTIAL APPLICATIONS IN THE BOSTON AREA 48

3.1 Projects Included in the Transportation Improvement Program 48

3.2 Southeast Expressway Ramp Metering 51

4.0 Transit-related Measures 53

INTRODUCTION 53

POTENTIAL APPLICATIONS IN THE BOSTON AREA 54

4.1 Fuel-Economy Measures 54

4.2 Major Capital Projects 59

4.3 Expansion of Bus Routes 66

4.4 Increases in Service Frequency 69

4.5 Fare Reductions 71

4.6 Upgrading, Maintenance, and Rehabilitation of Equipment and Facilities 73

4.7 Provision of Additional Park-and-Ride Lots 75

5.0 Increased Use of Carpooling and Vanpooling 77

6.0 Variable Work Hours 83

7.0 Bicycling 87

8.0 Additional Measures 91

8.1 Shared-Ride Taxi 91

8.2 Pricing Measures 92

8.3 Substitution of Communications for Transportation 94

8.4 Vehicle Restrictions 94

9.0 Summary and Conclusions 97

9.1 Program Costs 97

9.2 Summary and Evaluation of Measures 103

9.3 Project Review and Program Monitoring 108

LIST OF FIGURES AND TABLES

FIGURES

2-1 McClellan Highway - Entry to Sumner Tunnel 33

2-2 Configuration of Possible Reserved Lane on the Massachusetts Turnpike 36

TABLES

1-1 Fuel-Economy Standards and Statewide-Fleet Averages 4

1-2 Energy Consumption by Mode 5

1-3 1981 Boston-Region Vehicle-Miles Traveled 8

2-1 I-93: Projected Impacts of Priority-Lane Extension 19

2-2 Southeast Expressway: Projected Impacts of Contra-flow Lane 26

2-3 Southeast Expressway: Projected Impacts of Priority Bypass Lane at Neponset Ramp 28

2-4 Route 3: Projected Impact of Exclusive HOV Lane 30

2-5 Route 1A: Projected Impact of Reserved HOV Lanes 34

2-6 Massachusetts Turnpike: Projected Impact of .7-Mile Reserved Lane 38

2-7 Boston Traffic-Control System: Candidate Sections for Bus Priority 39

2-8 Estimated Impacts of Priority-Signal Treatments in City of Boston 42

3-1 Traffic-Flow-Improvement Measures 44

3-2 Transportation Improvement Program 1984-1988: Traffic and Signal Improvement Projects 49

4-1 Transit Fuel-Economy Measures 56

4-2 MBTA: Completed Energy-Conservation Programs 57

4-3 MBTA: Energy Programs 58

4-4 Major Capital Projects: Reduction in VMT-related Energy Consumption 60

4-5 Rail Transit Extensions: Net Energy Impacts 64

4-6 Transportation Improvement Program 1984-1988: Projects Likely to Have Ridership Impacts 74

9-1 Comparison of Program Costs for Potential Energy-Conservation Measures 98

9-2 Comparison of Measures 110

1.0 INTRODUCTION: STUDY OBJECTIVES AND EXISTING CONDITIONS

1.1 Study Objectives

It is now more than a decade since the nation was alerted to the problems of energy shortages and energy-price increases. During the 1970s, these problems emerged in the form of several price shocks and acute gasoline supply shortfalls, which caused widespread public alarm. Setting energy policy became an important government priority, and energy consumption in the transportation sector became an object of particularly intense scrutiny. One product of this concern was an interest in transportation-related energy-conservation measures, including energy contingency programs. In 1982, the Central Transportation Planning Staff prepared an Energy Contingency Plan for the Boston Region, at the request of the Executive Office of Transportation and Construction. That plan, which is explictly oriented to emergency conditions, identifies programs which could be put into effect in the event of future disruptions in energy supplies. The present document, however, addresses the need for conservation on a continuous basis, as a response to circumstances of chronic, rather than acute, energy shortage.

The key focus of this report is identification of potential conservation measures and estimation of their likely impacts on energy consumption. Most of the measures considered could be classified as low capital, Transportation Systems Management (TSM) actions, although several capital intensive transit projects are included due to their potentially large energy impacts. Also addressed in the process of comparing these measures are the following:

- project and program costs, including cost per unit of energy saved
- impacts on mobility and travel time
- economic and institutional feasibility

The report concludes with recommendations for establishing project review and program monitoring procedures.

1.2 Conservation in the 1980s

Preparation of this report at the present time raises questions concerning the need for energy conservation in a period of relatively stable energy prices and supplies. Since 1981 the world price of oil has actually declined, from a high of more than $35 to less than $30 per barrel. Oil imports and per capita consumption of oil have also declined during this period. In 1982,

U. S. oil imports dropped to 12.5 percent of domestic consumption, the lowest share since 1972. Data for the state of Massachusetts reflect the trend of declining energy consumption. Department of Revenue figures show that taxable gasoline purchases dropped during each of the five most recent years for which data are available, from a high in 1978 of 2.4 billion gallons to 2.2 billion gallons in 1982.[1]

The key unknown obviously is the future of energy prices and supplies. The oil glut of the past few years can be attributed in large measure to worldwide economic recession. The National Energy Policy Plan, released by the U. S. Department of Energy in 1983, forecasts declining world oil prices in real terms until the mid-1980s, and moderately increasing prices from 1985 to 1990. Industry analysts cite two factors likely to contribute to increasing prices:

- economic recovery
- anticipated increases in natural gas prices, which will, as a "spillover" effect, serve to increase the demand for oil

The importance of public conservation programs is therefore likely to persist and even increase over the next five years. The most critical phases of the energy crisis may possibly be past, but prices, which currently approach highest-ever levels, will almost certainly rise at a substantial rate over the next five years. In addition, energy markets remain volatile, and sudden disruptions in supply and precipitous price increases remain a strong possibility. The need for public conservation efforts thus continues; the current lull in the upward trend of energy prices can be viewed as an opportunity to carefully analyze prospective policy options and programs.

1.3 The Effect of Change in Auto Technology

In accordance with mandates set forth in the Energy Policy and Conservation Act of 1975, the federal government established regulatory fuel-economy standards for the domestic new-car fleet, beginning with the 1978 model year. These standards required staged increases in the new-car fleet average from 18.0 mpg in 1978 to 27.5 mpg in 1985. The Massachusetts Department of Public Works has estimated that as a result of these standards, the fuel economy of the entire statewide auto fleet, including both new and old vehicles, will have increased from a rate of 15.9 mpg in 1980 to 20.5 mpg in 1985 and 25.0 mpg in 1990.[2] The annual fuel-

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[1]Data for the first six months of 1983 indicate an increase in taxable gasoline purchases over the same period in 1982.

[2]Massachusetts Department of Public Works, Northeast Corridor Regional Modeling Project, Massachusetts Mobile Source Emission Data, February 1981.

economy standards and estimated fleetwide averages for the state are shown in Table 1-1.

The effect of increased auto fuel economy is a substantial reduction in total fuel consumption in the transportation sector. The reduction in taxable purchases of gasoline between 1978 and 1982, noted previously, can be attributed largely to improved vehicle fuel economy; this decline in fuel purchases of 9 percent occurred during a period when statewide vehicle-miles of travel increased by 5 percent. The Department of Public Works has estimated that statewide highway consumption of motor fuels will further decline by approximately 2 percent annually for the four-year period from 1983 through 1987. This translates into a cumulative savings over this period of 468 million gallons, or a one-year savings in 1987 of 178 million gallons, compared to 1983 consumption levels.

Increasing auto fuel economy is thus a powerful energy-conservation measure and almost certainly represents the most effective mechanism available to reduce consumption in the transportation sector. The savings achieved through this means can be regarded, for purposes of this report, as an element of background or existing energy conditions, since the technological developments responsible for these savings are unrelated to any potential state or regional policies.[1] The central concern of this report is to determine how the Boston MPO can contribute to achieving additional energy savings through changes in regional transportation systems or the use of these systems.

1.4 Energy Consumption by Transportation Mode

A comparison of energy consumption rates for different modes helps to place in perspective the significance of recent improvements in auto fuel economy. Table 1-2 presents data on modal energy consumption per vehicle mile and per passenger-mile. The table accounts not only for propulsion energy, but also for the energy expended in maintenance and manufacture of vehicles and in construction of guideways.[2] Early energy studies were often criticized for ignoring energy consumed in the construction and manufacturing of transit systems. This same argument applies to the analysis of fuel consumption by automobiles. Taking into account all categories of energy consumption, the estimated 1985

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[1]Throughout this report, references to the auto fuel-consumption rate refer to the 1985 statewide-fleet average, unless otherwise indicated. The effects of cold starts on fuel economy are not explicitly taken into account, in keeping with the general level of precision of the estimates presented in this report.

[2]See Congressional Budget Office, Urban Transportation and Energy: The Potential Savings of Different Modes, December 1977.

TABLE 1-1

Fuel-Economy Standards and Statewide-Fleet Averages

	Federal New Car Fleet Standard (Miles per Gallon)	Estimated Statewide Average New and Old Autos (Miles per Gallon)
1978	18.0	NA
1979	19.0	NA
1980	20.0	15.9
1981	22.0	16.5
1982	24.0	17.4
1983	26.0	18.3
1984	27.0	19.4
1985	27.5	20.5
1986	27.5	21.5
1987	27.5	22.5
1988	27.5	23.4
1989	27.5	24.0
1990	27.5	25.0

Source: Massachusetts Department of Public Works, Northeast Corridor Regional Modeling Project.

NA - not available

TABLE 1-2

Energy Consumption by Mode
(Btu's per Vehicle-Mile)

Mode	Propulsion Energy	Additional Operating and Construction Energy**	Total Energy Consump.	Average Occupancy	Total Energy Consumption per Passenger Mile
Average automobile	6,100*	3,225	9,325	1.4	6,660
Carpool	6,100*	3,225	9,325	3.0	3,110
Vanpool	7,750*	4,200	11,950	9.0	1,300
Dial-a-Ride	8,600*	4,200	12,800	1.6	8,000
Heavy rail (old)	61,000	13,500	74,500	20.0	3,100
Heavy rail (new)	75,000	20,500	95,500	21.0	4,550
Commuter rail	105,000	20,200	115,700	40.0	2,900
Light-rail transit	75,000	10,700	85,700	20.0	4,280
Bus	30,000	2,470	32,500	11.5	2,820

*1985 estimated fleet-wide average for Massachusetts.

**Includes: station and maintenance energy; construction energy; and vehicle manufacturing energy.

Source of data on propulsion energy for transit, additional operating and construction energy and average occupancy: Congressional Budget Office, Urban Transportation and Energy: The Potential Savings of Different Modes, December 1977.

average fuel-consumption rate for the Massachusetts auto fleet is 13.4 mpg, whereas the rate is 20.5 mpg in terms of propulsion energy alone.

Vanpooling emerges in the table as the most energy efficient of all modes on a passenger-mile basis. The following modes consume just under half as much energy per passenger-mile, at average nationwide occupancy rates, as an automobile with 1.4 occupants: buses, commuter rail, old heavy rail transit systems, and carpools. New heavy rail systems and light-rail transit consume approximately two-thirds the amount of energy per passenger-mile as an average automobile. The only mode which is less energy-efficient than the automobile is Dial-a-Ride paratransit.

When comparing the energy impacts of specific transportation programs or projects, it is also necessary to take into account such factors as: access mode and distance, trip circuity, and former or alternative mode. All of these factors tend to work to the disadvantage of transit, particularly rail systems. For example, the predominant mode of access to commuter rail and new heavy-rail systems is often auto, and accounts, on average, for close to 20 percent of total trip distance. Accounting for the energy consumed in accessing the transit system thus reduces the relative advantage of transit line-haul trips relative to trips made entirely by auto. The value of transit in energy conservation therefore needs to be evaluated on a project-specific basis, since such factors as access mode can then be quantified. As a rule, however, the data indicate that reducing the use of automobiles by increasing transit ridership remains a sound conservation policy.

This general rule is particularly valid for high density regions such as the Boston metropolitan area. The auto fuel-consumption rate presented in Table 1-2 is a statewide average, while a disproportionate amount of auto travel in the Boston metropolitan area occurs under congested traffic conditions which reduce fuel economy. During peak periods, of course, transit load factors are much higher than those shown in the table, and much less energy is consumed per transit-passenger-mile.

Of even greater importance, perhaps, are certain indirect sources of energy savings associated with transit service. Most studies of energy consumption in the transportation sector, including this one, focus on differences in the fuel economy of alternative modes on a per-passenger-mile basis. The relative advantage of transit service with respect to fuel-consumption rates, as discussed above, can be considered direct savings, and it is this category of benefits which is easiest to quantify. However, there are much broader, indirect energy impacts associated with alternative forms of transportation; these are difficult to quantify and are most often ignored. Specifically, urban areas with high levels of transit service generate higher-density land-use development, which in turn results in the

following secondary effects:[1]

- the number of vehicle miles traveled (VMT) per person and per household tend to be lower than in less densely developed urban areas, due to shorter average trip distances and less frequent use of automobiles, which is related in part to lower auto ownership rates

- space heating is more energy efficient in the case of multi-family residential dwellings, which are characteristic of high-density land-use development, than in single family homes

It may be difficult to forecast the land-use impacts associated with individual transit projects, but it is clear that on a cumulative basis, investments in rail transit and other major improvements in public transportation services will produce far-reaching improvements in energy-consumption patterns. Reports such as this, which focus narrowly on measures of per-passenger fuel efficiency, will inevitably understate the potential contribution of large-scale transit projects to energy conservation.

1.5 Fuel Consumption in the Boston Region

Table 1-3 shows 1981 vehicle-miles of travel (VMT) for all municipalities in the Metropolitan Area Planning Council region. Annual VMT for the region as a whole totaled approximately 11.7 billion. Assuming a two-percent annual rate of growth, 1985 regional VMT is estimated at 12.7 billion. Applying an average fleet-wide fuel-consumption rate of 18.2 mpg,[2] it is estimated that total highway fuel consumption will equal 698 million gallons. This figure may be considered to represent the baseline energy-consumption level in the region's transportation sector.[3] The estimated impacts of potential conservation measures are evaluated in this report, in relation to this benchmark.

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[1]See Executive Office of Transportation and Construction, Matthew A. Coogan, "Public Transportation Services and the Conservation of Energy, a White Paper",

[2]Fleet mix includes autos, trucks and buses.

[3]While this figure excludes electric energy consumed in operating rail transit, highway fuel consumption represents close to 100 percent of the total consumed in the transportation sector.

TABLE 1-3

1981 Boston-Region Vehicle-Miles Traveled
(in 00's)

Daily Vehicle-Miles Traveled by City/Town:

Acton	3,932	Franklin	2,324	Milford	3,155	Stoughton	4,288
Arlington	3,921	Gloucester	5,092	Millis	1,075	Stow	702
Ashland	1,639	Hamilton	1,097	Milton	6,809	Swampscott	1,223
Bedford	3,474	Hanover	2,687	Nahant	557	Topsfield	1,519
Bellingham	2,768	Hingham	4,915	Natick	6,113	Wakefield	4,836
Belmont	2,870	Holbrook	1,730	Needham	6,639	Walpole	3,521
Beverly	5,475	Holliston	2,085	Newton	12,942	Waltham	8,688
Bolton	2,083	Hopkinton	3,115	Norfolk	658	Watertown	1,903
Boston	66,252	Hudson	1,995	No. Reading	1,662	Wayland	3,542
Boxborough	1,336	Hull	1,349	Norwell	3,282	Wellesley	5,414
Braintree	10,320	Ipswich	1,521	Norwood	4,536	Wenham	1,310
Brookline	4,632	Lexington	10,659	Peabody	6,894	Weston	7,223
Burlington	7,331	Lincoln	2,629	Pembroke	1,830	Westwood	3,885
Cambridge	8,351	Littleton	3,306	Quincy	11,854	Weymouth	7,383
Canton	7,177	Lynn	5,423	Randolph	6,814	Wilmington	6,777
Carlisle	424	Lynnfield	4,006	Reading	3,567	Winchester	2,338
Chelsea	3,360	Malden	3,584	Revere	8,017	Winthrop	1,093
Cohasset	1,559	Manchester	2,026	Rockland	1,957	Woburn	9,235
Concord	4,336	Marblehead	1,750	Rockport	1,207	Wrentham	2,128
Danvers	6,547	Marlborough	5,502	Salem	3,287		
Dedham	6,849	Marshfield	2,804	Saugus	5,950		
Dover	1,177	Maynard	1,221	Scituate	2,677		
Duxbury	3,160	Medfield	1,603	Sharon	4,745		
Essex	526	Medford	8,581	Sherborn	1,065		
Everett	2,359	Medway	1,501	Somerville	6,809		
Foxborough	4,485	Melrose	1,883	Southborough	4,183		
Framingham	10,840	Middleton	1,552	Stoneham	5,115		

Total daily vehicle-miles traveled for Boston region: 46,740,800
Total annual vehicle-miles traveled for Boston region: 11.7 billion

Source: Massachusetts Department of Public Works

2.0 PREFERENTIAL TREATMENT FOR HIGH-OCCUPANCY VEHICLES

BACKGROUND: TYPES OF ACTIONS

There is a wide range of measures which may be used to provide preferential treatment for high occupancy vehicles (HOVs). These measures are all designed to improve highway travel conditions for selected categories of vehicles, which may be limited to buses only or may, in some cases, include carpools and vanpools as well. Preferential or priority treatments are generally appropriate only on segments of the highway network which regularly experience congestion, since the purpose of preferential treatment is to alleviate delays for priority vehicles.

The reduction of delays results in improved travel time, operating speeds, and reliability for vehicles designated for priority treatment. However, the same measures which are used to selectively improve the operation of high occupancy vehicles may have a detrimental effect on travel conditions for non-priority vehicles. In fact, priority measures can aggravate existing traffic problems if they are applied inappropriately.

Some prospective priority-treatment applications in the Boston area are likely to involve reductions in roadway capacity for non-priority vehicles, at least during peak periods. This may result in diminished total roadway capacity, defined in terms of vehicle-trips per hour. However, successful applications of priority treatments will generally increase the number of person trips which are accommodated on a congested roadway, since buses and other high-occupancy vehicles are substantially more efficient at transporting people than single-occupant automobiles. The primary criterion which is commonly used in evaluating specific applications of priority treatments is whether they will actually increase the number of people who are carried in the peak direction on a given facility.[1]

This criterion reflects traffic-management considerations rather than an explicit concern for energy conservation. The need to conserve energy may vary over time, depending on energy supply and cost. However, the importance of increasing the efficiency of the transportation system, in terms of optimizing the peak-hour capacity of key existing facilities, will persist. Energy-conservation strategies which derive from sound traffic-management policies therefore tend to be the most practical.

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[1]National Cooperative Highway Research Program, Report 155, Bus Use of Highways, Planning and Design Guidelines, 1975, p. 20.

In the case of preferential treatment of high occupancy vehicles, energy savings result from two sources:

1) Improved traffic flow for priority-designated vehicles: the reduction in delays, and consequent increases in operating speeds, will lower fuel-consumption rates for buses and, where applicable, other high-occupancy vehicles. Traffic-flow-related energy savings may be offset, however, if congestion increases among non-priority vehicles.

2) Increased use of transit and other high-occupancy modes: improved travel times and reliability for high-occupancy vehicles should result in mode shifts from single-occupant automobiles.

Different forms of preferential treatment may be applied on freeways and on urban arterials. Whereas freeway-related treatments may be successfully implemented on a single-facility basis, arterial treatments generally require more widespread, coordinated application if they are to result in significant improvements in transit-vehicle operations and fuel-consumption savings. In general, systematic development of HOV-priority measures throughout a corridor, city, or region will increase the effectiveness of both arterial and freeway treatments. Measures which may be implemented in downtowns or activity centers are a subset of those which are suitable for urban arterials. The range of measures which are suited to both freeway and arterial applications is identified below.

Freeway-Related Projects

- Busways

Busways provide an exclusive right-of-way for buses which is usually separated from regular highway traffic. Busways may be located beside highways, along highway medians, or in former railroad rights of way. New construction is generally required to establish a busway.

Busways differ from other priority treatments in two principal respects:

- A significant capital expenditure is usually required for their construction.

- Busway operations do not conflict with regular traffic. In fact, removal of buses to a separate right-of-way will improve traffic flow for non-priority vehicles.

The level of service made possible by busways may under certain circumstances approach that of rail transit, since bus operations are unencumbered by traffic. However, since this form

of priority treatment is relatively expensive, it is suitable only in situations where bus volumes are of sufficient magnitude to justify the cost. The suggested range in volumes required to support busway construction is 40-60 peak-hour buses traveling in one direction.[1] Busways are therefore feasible only on major corridors in large metropolitan areas. An additional constraint on busway applications is, obviously, the need for sufficient space to accommodate the right-of-way. This can be a significant consideration in dense urban corridors, and few exclusive-right-of-way facilities for buses have been constructed. In-median busways are in operation on the San Bernardino Freeway in Los Angeles and the Shirley Highway in the Washington, D.C. metropolitan area. The South Patway in Pittsburgh is a busway located on a separate right-of-way, and a continuation of I-66 in northern Virginia which will be designated for exclusive bus/HOV use is under construction.

- Reserved HOV Lanes

An alternative to the construction of exclusive busway facilities is the provision of reserved bus or high-occupancy lanes on existing highways. The chief advantages of this form of priority treatment, relative to busways, are lower costs, greater flexibility, and better access to other segments of the highway network.[2] The level of capital expenditure required to establish a priority freeway lane is fairly low, the costs consisting chiefly of signing, signalization, physical barriers, and, in some cases, access ramps.

Reserved lanes may operate in the same direction as the other traffic on the same side of the freeway median (concurrent flow) or in the opposite direction (contraflow). Reserved-lane provisions are usually in effect only during one or both daily peak periods. If only one lane is to be designated for the exclusive use of high-occupancy vehicles, the reserved lane will generally be in effect during the AM peak only, unless the lane is located within the highway median, in which case it can be reversed during the PM peak.

A <u>concurrent-flow</u> reserved lane can be located in the curb lane, the inside lane (next to the median) or in the median lane (if one exists or can be created). In most cases to date, it is the inside lane which has been reserved for high-occupancy vehicles, to avoid conflicts with entrance and exit ramps. The creation of a concurrent-flow lane is possible only if there is a total of three freeway travel lanes in the peak direction, or two

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[1] Public Technology, Inc., <u>Manual on Planning and Implementing Priority Techniques for High Occupancy Vehicles: Technical Guide</u>, U. S. Department of Transportation, July 1977, p. 135.
[2] Ibid., p. 147.

lanes in addition to a median lane. If fewer than two travel lanes were provided on a freeway for non-priority vehicles in the peak direction, then breakdowns, accidents, or other traffic-flow interruptions could result in massive traffic delays, and non-priority vehicles would be tempted to intrude into the reserved lane. A concurrent-flow lane can be designated simply by a diamond-shaped pavement marking, which is the standard symbol for an exclusive bus lane, and appropriate signing. A minority of concurrent-flow HOV lanes established to-date have physical barriers. Concurrent-flow HOV treatments currently in operation range in length from the "queue jumper" of 1.4 miles on Boston's I-93 to the 7.5-mile reserved bus lanes on I-95 in Miami, Florida.[1]

Travel-time changes also vary substantially for different concurrent-flow projects, in terms of both total and per-mile travel-time changes. Total travel time savings for priority vehicles range from 1.0-1.5 minutes for the 3.3-mile Banfield Freeway project in Portland, Oregon to 5 minutes for Miami's I-95 project. The per-mile travel-time-savings rate for priority vehicles varies from 0.4-0.6 minutes per mile on the Banfield Freeway to 5-12 minutes per mile on Boston's I-93 preferential lane. The effects of concurrent-flow projects on non-priority vehicles have been mixed, ranging from a savings of four minutes in total travel time (.4 minutes per mile) on I-93 in Miami to an increase of 8.8 minutes (1.1 minutes per mile) on Boston's Southeast Expressway during the Diamond Lane's brief period of operation.[2]

Experience has shown that public opposition and political pressure are apt to defeat concurrent-flow projects on grade-separated facilities if they require the elimination of a general traffic lane. This occurs even when these projects are cost-effective and otherwise justifiable in terms of technical performance criteria. Boston's Southeast Expressway Diamond Lane experiment provides a cogent illustration of the political obstacles associated with these projects. Several existing concurrent-flow HOV lanes were created by eliminating or reducing the width of freeway shoulders, rather than removing a travel lane. This strategy successfully mitigates public opposition, though it may result in serious safety and enforcement problems.[3]

Contra-flow reserved lanes are always placed adjacent to the highway median. They are appropriate only on freeways where there is a substantial imbalance in traffic flows between the

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[1]Morris J. Rothenberg and Donald R. Samdahl, Evaluation of Priority Treatments for High Occupancy Vehicles, FHWA/RD-80/062, January 1981, pp. 106-111.
[2]Ibid., pp. 112-117.
[3]Ibid., p. 93.

peak and off-peak directions, with excess capacity in the off-peak direction. Physical barriers are required to separate reserved contra-flow lanes from the traffic lanes operating in the reverse direction. Most often, removable stanchions or pylons are installed and removed daily before and after the periods when the lanes are reserved for priority vehicles.

The majority of contra-flow-lane projects implemented to-date have operated in one direction only, and have been limited exclusively to buses. However, there are examples of contra-flow lanes which are in effect during both peak periods, as well as several which permit use by HOVs other than buses. Notably, the North Freeway Contra-flow Project in Houston, Texas is open to vanpools as well as buses, and the contra-flow lane on the Long Island Expressway permits use by both buses and taxis. Safety concerns have been the primary motivation for restricting contra-flow lanes to buses only or, in a few cases, other selected categories of HOVs. However, the excellent safety record of contra-flow lanes, resulting from both high visibility and limited accessibility, suggests that use by carpools is a possibility for properly designed projects.

The results of a recent study show that bus travel-time savings for three contra-flow projects (I-495 - Lincoln Tunnel Approach; Long Island Expressway; U. S. 101 - San Francisco) ranged from 4 to 10 minutes, or 0.9-5.0 minutes per mile. In the case of two of these projects, travel-time savings were also experienced by non-priority vehicles traveling in the peak direction.[1]

- Priority Freeway Access

Priority access for high-occupancy vehicles may be provided with either exclusive bus/HOV ramps, or bus/HOV bypass lanes on metered ramps. These are commonly used techniques in cases where HOV highway lanes are infeasible. Priority access is obviously most effective as a preferential treatment measure in situations where traffic delays are regularly experienced on highway entrance ramps. Depending on the volumes of HOV ramp traffic, priority-access techniques may be applied to carpools and vanpools, as well as buses.

Exclusive bus or HOV access ramps can be implemented on any highways where the physical opportunity permits. Physical requirements include adequate spacing between the priority ramp and other ramps, to accommodate peak-period merging and weaving movements.

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[1]Ibid.

Priority bypass lanes represent a highly cost-effective means of providing preferential access for high-occupancy vehicles. This strategy is broadly applicable on facilities where physical constraints preclude the construction or designation of exclusive priority ramps. Priority bypass lanes are generally the left lanes of freeway ramps. Often, ramp metering accompanies preferential-bypass treatments. In these cases, bypass lanes are exempt from meter-ramp signals. Metering itself can conserve energy through its beneficial effect on traffic flow, as discussed in Section 3.0 of this report.

Ramp-meter-bypass projects are common in Los Angeles, and there are a number of priority ramp treatments which have been implemented in other metropolitan areas. Reported travel-time savings for these projects have ranged form 0.6 to 5.0 minutes. Generally, carpools as well as buses have been treated as priority vehicles.[1]

Arterial-Related Actions

- Reserved HOV Lanes

Bus services in most metropolitan areas are concentrated to a far greater extent on city streets than on grade-separated facilities, many of which bypass the city center. In addition to local bus operations, express buses often use downtown streets for distribution, and, in the Boston area, arterials serve the line-haul segment of several express bus routes. It is therefore not surprising that bus priority treatments on arterials currently outnumber those on freeways.[2]

As on freeways, reserved lanes on urban arterials may operate in either a concurrent or contra-flow direction. Reserved lanes may be created on arterials by adding a lane, through the removal of on-street parking or the narrowing of existing traffic lanes. More commonly, reserved lanes have been accommodated by removing a general-traffic lane. A variation of the reserved-lane concept is the busway or bus street, which reserves an entire roadway, usually in a downtown center, for the exclusive use of buses.

As a rule, HOV lanes should be considered only on arterials which meet minimum requirements of three lanes in a single direction (a total of six lanes total on a two-way street), or two lanes in each direction on a two-way street plus a median lane.[3]

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[1]Ibid., p. 85.
[2]NCHRP Report 155, Bus Use of Highways, p. 103.
[3]Manual on Planning and Implementing Priority Techniques for High Occupancy Vehicles, pp. 186-188.

There are several alternative traffic-engineering standards which may be applied to determine whether a particular arterial segment is suited to reserved-lane treatments. The Institute of Traffic Engineers and the Transport and Road Research Laboratory in Britain recommend minimum volumes of 60 and 40 peak-hour buses, respectively, for curb bus lanes. These standards should be relaxed if there are special policy considerations which support the development of exclusive bus facilities, or if carpools are permitted to use reserved lanes.[1] Most of the reserved-arterial-lane projects currently in operation treat only buses as priority vehicles. However, there are a number of examples of concurrent-flow arterial projects and one contraflow lane which are open to carpools.

Reserved arterial lanes implemented thus far have generally resulted in measurable travel-time savings for priority vehicles. Total priority-vehicle travel-time savings for concurrent-flow arterial treatments averaged one to three minutes, or 0.5 to 1.1 minutes/mile, in a recent study. This benefit was offset to some degree by increases in travel time and congestion for non-priority vehicles.[2] From the standpoint of energy conservation, this may be a serious drawback, since congested travel conditions tend to increase fuel consumption. Priority-vehicle travel-time savings for contra-flow projects have exceeded those recorded for most concurrent-flow projects, ranging as high as 15 minutes (1.0-2.2 minutes per mile) under highly congested conditions.

- Priority Signalization

Priority signalization treatments may include preemption or other signal modifications which facilitate the flow of priority vehicles. These measures can have significant impacts on the quality of bus service; studies show that signal-related delays typically account for 10 to 20 percent of overall bus trip times and 50 percent of deviation from schedule.[3] Generally, priority signal treatments are applied only to buses. However, if priority signals are implemented in conjunction with reserved HOV lanes, they may also be applied to carpools.

Signal preemption is the advancement or extension of signal green time, or addition of a green signal phase, for priority vehicles. "Active" systems involve the use of on-bus electronic emitters, while "passive" systems detect the presence of HOVs through pavement loops or other stationary devices which do not require special equipment on the priority vehicles themselves.[4]

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[1]NCHRP Report 155, Bus Use of Highways, p. 118.
[2]Evaluation of Priority Treatments for High Occupancy Vehicles, p. 86.
[3]NCHRP Report 135, Bus Use of Highways, p. 121.
[4]Ibid.

Another approach is to modify signal timing so as to increase the percentage of green time on arteries which serve as major bus routes. Signal timing is normally designed to optimize vehicle throughput at intersections. Priority signal timing can be viewed, however, as a means to maximize intersection throughput in terms of person-trips, rather than vehicles. Signal preemption is most effective on arterials which carry from 10 to 30 buses per peak hour and have multiple coordinated signals.[1]

Signal adjustments may also include special left- or right-turn phases for buses. These warrant serious consideration whenever buses are required to turn in front of two or more traffic lanes which together serve over 500 peak-hour vehicles. Priority turn provisions may also involve exempting buses from turning restrictions which apply to other vehicles.[2]

POTENTIAL APPLICATIONS IN THE BOSTON AREA

There are currently few examples of preferential-treatment projects in the Boston area. Potential applications of these measures in the region are limited, due to the small number of roadways which meet minimum lane requirements and which are suitable in terms of HOV-usage levels. Potential arterial treatments, in particular, are essentially confined to priority signalization measures and (possibly) bus turning lanes, due both to roadway-capacity constraints and the lack of bus-volume concentrations. Rail transit is the heart of the public transportation system in the core of the Boston region, which limits the volume of bus traffic in and near the downtown. Many current bus routes are designed to feed into rapid- and light-rail stations, rather than the downtown, and are thus relatively dispersed. Buses entering the downtown street network via the Masssachusetts Turnpike are the single case in which volumes exceed the minimum standard for reserved arterial bus lanes (40-60 vehicles per peak-hour). Routing modifications, however, rather than reserved lanes, are probably the most potentially effective treatment for these routes.

Nevertheless, there are several limited-access highways which present possible preferential-lane opportunities in the Boston area; these are identified and analyzed below. An analysis of the potential for application of arterial-oriented preferential-signal treatments in Boston concludes this chapter.

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[1] Public Technology, Inc., Manual for Planning and Implementing Priority Techniques, p. 203.
[2] Ibid.

2.1 Extension of I-93 Preferential Lane

The I-93 preferential lane operates as a concurrent flow lane reserved for the use of buses and three-or-more-person carpools during the weekday morning peak period (6:30-9:30 AM). The lane, which is inbound and located to the north of the Central Artery Bridge in Charlestown, was 2,000 feet in length at its inception in February 1974. Since that time, the lane has been extended twice, and its present length is approximately 7,500 feet or 1.4 miles. Further extension of the lane northward is a possible improvement which would allow priority vehicles to bypass more of the prevailing traffic congestion.

A 1981 CTPS study recommended that extension of the preferential lane be given serious consideration. The study found that priority vehicles encounter congestion prior to entering the preferential lane, which reduces the relative advantage associated with the priority treatment. Traffic was frequently observed to reach congested levels as far north as Route 16, which is over two miles from the entrance to the lane. Average queue length during the peak hour (7:30-8:30 AM) was found to exceed the length of the priority lane by .1 mile. These conditions are the basis for the study's conclusion that an extension of the priority lane is warranted if it can be determined that the deterioration in travel conditions for general traffic would not exceed the benefits to priority vehicles.[1] An analysis is therefore required of the impacts on traffic flow and queue lengths which would be associated with extension of the preferential lane.

It should be noted that an extension of the preferential lane by more than approximately 2,000 feet would block access from the Sullivan Square/Mystic Avenue on-ramp to the Mystic-Tobin Bridge/Charlestown off-ramps. It was estimated in the CTPS study that this would affect no more than 125 vehicles, all of which could use Rutherford Avenue as an alternate route, with minimal increases in travel time.[2]

Traffic Impacts

The delays encountered immediately prior to the beginning of the preferential lane vary substantially from day to day. More detailed, current travel-volume data are required to determine the optimal length of a potential lane extension. For purposes of this report, average or typical maximum queue lengths are considered to exceed the length of the preferential lane by .1 to .25 miles, or 530 to 1,350 feet. Extensions of the preferential

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[1]Central Transportation Planning Staff, An Analysis of the I-93 Preferential Lane, July 1981.
[2]Ibid., p. 43.

lane by .17 miles (925 feet) and .44 miles (2,300 feet) would be required to bypass existing queues of .1 miles and .25 miles, respectively.[1] To illustrate the impacts of lengthening the preferential lane, extensions of .17 miles and .44 miles are analyzed below.

Average travel-time savings for HOVs (buses, and carpools with three or more passengers) would be 45 seconds during the peak hour, and 15 seconds during the entire peak period of 7:00-9:00 AM, if the preferential lane were extended by .17 miles. An extension of .44 miles would yield average peak-hour travel-time savings of 90 seconds and average peak-period travel-time savings of 30 seconds. Reductions in travel time this small in magnitude would not have a significant effect on modal choice; i.e., the distribution of auto, transit, and carpool passengers would remain unchanged.

It should be noted that an extension of the preferential lane to bypass the existing queue, which is related to the bottleneck at the Central Artery bridge, would not adversely affect the travel times of non-preferential vehicles. The effect on these vehicles would be to lengthen the queue physically, by .07 miles (370 feet) in the case of a .17-mile lane extension, or .19 miles (1,003 feet), in the case of a .44-mile extension. At the same time, however, travel speeds in these sections of the queue would increase from the current 8 mph to 14 mph, yielding identical travel times to those which existed prior to the lane extension. Thus, while the benefits to priority vehicles in terms of travel-time savings would be fairly marginal, there would be no adverse consequences to non-priority traffic. An extension of the lane therefore warrants consideration.

Fuel-Consumption Impacts

Since preferential-lane extensions between .17 and .44 miles in length would not significantly alter modal shares, there would be no significant decrease in vehicle-miles traveled (VMT) and thus no related decrease in fuel consumption. However, the potential remains for energy savings resulting from increased travel speeds. These potential impacts are examined below and summarized in Table 2-1.

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[1] For a discussion of the relationship between highway volume/capacity ratios and queue lengths on I-93 and other Boston-area roadways, see: Central Transportation Planning Staff, A Procedure for Predicting Queues and Delays on Expressways in Urban Core Areas, CTPS Technical Report 36, February 1983.

TABLE 2-1

I-93: Projected Impacts of Priority-Lane Extension

	Existing Lane	.17-mile (925-ft.) Extension	.44-mile (2,300-ft.) Extension
Number of Vehicles (7:00-9:00 AM)			
• 1- or 2-Passenger Autos	6,180	6,180	6,130*
• 3+ Passenger Autos	675	675	680*
• Buses	62	62	62
Decreases in Bus and Carpool Travel Times	--	Average Max.: .75 min. Avg. Peak Per.: .25 min.	Average Max.: 1.5 min. Avg. Peak Per.: .5 min.
Queue Speed (Non-Priority Vehicles)	8 mph	14 mph	14 mph
Fuel-Consumption Impacts	--	15 gallons/day 3,700 gallons/year	30 gallons/day 8,000 gallons/year

*Estimated modal change is not significant.

The speeds of both carpools and buses would increase over the extended-lane segment from 8 to 50 mph, as a result of improved traffic flow. The effect of this change in operating conditions would be a decrease in the rate of fuel consumption for individual vehicles. Fuel-consumption efficiency would also increase among non-preferential vehicles over that segment of the queue on which travel speeds would increase from 8 to 14 mph. However, the queue would be extended in length for non-priority vehicles, and over this extended distance travel speeds would decline from approximately 40 mph to 14 mph.

The net effect would be a small decrease in fuel consumption for non-preferential vehicles. In the case of the minimum lane extension of .17 miles, there would be a net decrease in fuel consumption by all vehicles of approximately 15 gallons per day, or 3,700 gallons per year. An extension of .44 miles would yield a savings of approximately 30 gallons per day or 8,000 gallons per year.

These impacts are small, since the lane extensions being considered are relatively short. If new data were made available which indicated that queues have increased as a result of growth in traffic volumes, a longer extension of the preferential lane might be justified. In that case, potential energy-conservation impacts would increase in magnitude.

2.2 Southeast Expressway - Contra-flow Bus Lane and Priority Ramp-Bypass

The Southeast Expressway, in combination with Boston's Central Artery, is the most heavily traveled highway in Massachusetts. Weekday volumes on the expressway, which has a design capacity of approximately 80,000 vehicles per day, average roughly 120,000 vehicles. Major traffic delays are commonplace during periods of peak commuter travel.

The expressway is the major commuter route connecting South Shore communities with Boston, and also serves large volumes of weekend traffic between the Boston area and recreational sites on the South Shore and Cape Cod. The facility spans a distance of approximately eight miles, from the junction of Routes 128 and 3 on the south to the Central Artery in downtown Boston.[1]

Two forms of reserved-lane treatments have been implemented on the expressway in previous years. A contra-flow bus lane was in effect during peak travel periods from 1971 through 1976. The lane, which operated in the northbound direction from 7:00 to

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[1]Central Transportation Planning Staff, Southeast Expressway Lane Allocation Study, CTPS Technical Report 20, August 1980, p. 1.

9:30 AM, was located in the southbound roadway alongside the median. A southbound contra-flow lane was introduced briefly during the PM peak, but was discontinued after a trial period of several weeks, during which it failed to produce significant travel-time savings. Travel-time savings in the northbound contra-flow lane were significant, resulting in a small increase in express bus ridership.

The contra-flow lane was discontinued in 1977, at the same time that a northbound-concurrent flow HOV lane, referred to as the "Diamond Lane" or "Downtown Express Lane," was introduced. This project was implemented in three successive stages. Phase 1 began on May 4, 1977, when the Massachusetts Department of Public Works (MDPW) reserved the left lane of the northbound roadway for the use of buses and three-or-more-occupant carpools during the hours of 6:30 to 9:30 AM. The objective of the reserved-lane treatment was to increase the capacity of the Expressway, which would be undergoing reconstruction over the next several years. Compliance with reserved-lane restrictions during this phase, as well as the subsequent Phase 2, was voluntary. Phase 2 started on June 2, 1977, when one of the northbound general traffic lanes was closed to accommodate construction.

Enforcement of the reserved lane began on October 8, 1977, through the issuing of traffic tickets to violators, marking the start of Phase 3. This mandatory-compliance phase lasted only two weeks, until November 2. During this period, a continuing trend of commuter shifts to high-occupancy vehicles was evidenced. While express-bus ridership increases were small, the use of rapid rail and carpools increased significantly; a shift to alternative modes is estimated to have occurred among 10 percent of former single-occupant-auto users.[1] Nevertheless, the Downtown Express Lane project was terminated after a very brief trial period, due to intense public opposition and political pressure. It should be noted that this experience is not unusual; as noted in an earlier section of this report, concurrent-flow lanes which are established by eliminating existing general-travel lanes rarely achieve public acceptance. Since the end of the Downtown Express Lane experiment, there have been no reserved HOV lane treatments in effect on the expressway.

Reconstruction of the expressway is scheduled to occur during 1984 and 1985. It has recently been decided that the reconstructed expressway will retain its current basic design configuration, which is four lanes, consisting of three travel lanes and one breakdown lane, in each direction (the "4-4" design). A 1980 CTPS report (see last footnote) analyzed alternative design configurations and traffic-management options for

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[1]Ibid., pp. 2-4.

the reconstructed expressway. The design options included both the "4-4" configuration, which was ultimately chosen, and a "3-2-3" configuration, consisting of three lanes in each direction, plus two reversible median lanes.[1] While the rejected "3-2-3" option would have accommodated a broader range of reserved-lane treatments, the possibility of implementing a contra-flow bus lane in conjunction with a "4-4" configuration remains. Another possibility, which could be compatible with the contra-flow lane, would be one or more priority ramp-bypass treatments. These would be most effective if implemented in conjunction with ramp metering.

Traffic Impacts

- Contra-Flow Lane

In the CTPS study referred to previously, it was estimated that a northbound AM contra-flow bus lane would result in an express bus ridership increase of 12 percent or 400 passengers during the AM peak period. The predicted impact on traffic volumes was a decline of 200 vehicles in the general traffic lanes, from 19,400 to 19,200 vehicles, and an increase in buses from 100 to 115. It was also estimated that the contra-flow lane would yield net travel-time savings in excess of 69,000 hours per year. These estimates did not account for the rapid growth which is occurring in the South Shore corridor, and are likely, therefore, to understate contraflow impacts by as much as 50 to 100 percent. Bus ridership increases should, thus, be regarded as ranging from 400 to 800 passengers, while auto traffic volumes can be expected to decline by 200 to 400 vehicles.

Earlier in this section it was noted that a southbound contra-flow lane in effect on the expressway during the PM peak period was discontinued after a brief trial in 1971, due to insufficient impacts on travel time. Traffic conditions on the expressway generally tend to be better during the afternoon peak period than the morning peak, probably due to a greater dispersion of departure times for work-to-home trips. Thus, it is reasonable to expect that a southbound PM contra-flow bus lane would yield impacts of lesser magnitude than a northbound AM bus lane.

For purposes of this analysis, average travel speed in the general-traffic lanes is assumed to be 40 mph during the PM peak period, compared to the average AM-peak-period speed of 34 mph reported in the 1980 CTPS study.[2] Using the same methodology

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[1] Ibid., p. 91.
[2] The CTPS report did not include an analysis of a southbound PM contra-flow lane.

employed in that study[1] (modified to reflect possible impacts of population increases), an increase in peak-period transit ridership of 6 to 12 percent, or 250-500 passengers, has been estimated for the PM peak. The impact on peak-period traffic volumes would be a decrease of roughly 135 to 270 vehicles, above the 200-400-vehicle decline attributable to the AM contra-flow lane.

The magnitude of impacts associated with the contra-flow lane is limited by the fact that buses do not represent the principal form of transit serving the South Shore corridor. The Red Line rapid transit service is apt to be superior to most potential express bus operations which would utilize the expressway. The long-term market for expanded bus services, even those which offer reduced expressway travel times relative to automobiles, is thus relatively small. This underscores the advantage of providing incentives for carpools as well as buses. However, contra-flow lanes on limited access facilities are rarely open to carpools, as has been noted previously. The implementation of a concurrent flow lane on the expressway that could accommodate HOVs other than buses is likely to be unacceptable on political grounds.

- Priority Ramp-Bypass

Priority bypass treatments were not considered in the 1980 CTPS study, since these can be implemented only on two-lane ramps, and Neponset is the only ramp which meets this requirement. (The Neponset ramp currently has only one lane in operation, because the DPW has blocked off the use of one lane.) It was also judged that travel-time savings associated with a ramp bypass would be too small to be a significant incentive to HOV use.

Examination of the travel times on four of the northbound expressway entrance ramps (Furnace Brook Parkway, Granite Avenue, Neponset Circle, Columbia Road), as reported in the CTPS study, reveals that ramp congestion was not severe. The greatest congestion-related delays occured on the Neponset ramp, and these did not tend to exceed three-fourths of one minute. However, the report did not account for the effects of blocking off one of the two lanes on the Neponset ramp, which has increased delays preceding entry onto the expressway. Priority bypass at the

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[1]Estimates of bus-ridership increases are based on a travel-time elasticity value of 1.10. This is the line-haul elasticity for large "multi-nucleated cities" reported by Y. Chan and F. L. Ou in "A Tabulation of Demand Elasticities for Urban Travel Forecasting." The figure was used to accurately project bus ridership for both the Downtown Express Lane project in 1977 and the contra-flow operation in 1970-71.

Neponset ramp thus merits further examination in conjunction with a ramp-metering strategy.[1] Under this scenario, the lane which is currently closed to all traffic would be opened to HOV use only. It should be noted that the inducement of greater carpool use through a project of this type may occur partially at the expense of Red Line ridership. The magnitude of this potential negative impact would also bear investigation prior to project implementation.

Fuel-Consumption Impacts

- Contra-flow Lane

Energy-impact estimates are presented below for both one-way (AM) and two-way (AM and PM) contra-flow-lane operations. These estimates have been calculated using MDPW projections of the 1985 vehicle-fleet average fuel-consumption rate (20.47 mpg for autos; 6.38 mpg for buses). The number of two-way automobile trips eliminated as a result of contra-flow-lane operation (200-400 for AM only, 325-670 for AM and PM) have been converted to VMT, assuming an average one-way trip length of 12 miles, or 24 miles round trip. The energy-consumption estimates also reflect a calculation of the VMT associated with expansion of bus services in conjunction with contra-flow operations (15-30 additional bus round trips for AM only, 24-48 additional bus round trips for AM and PM operations combined).

The effect of reduced traffic congestion on bus-related fuel consumption is also reflected in the estimates, by adjusting the fuel-consumption rate (in gallons consumed per mile) to account for changes in the quality of traffic flow. This adjustment is based on the documented relationship between fuel-consumption rates and average travel times, in minutes per mile, for urban travel.[2] Under urban travel conditions, where average travel speeds tend to be limited by disruptions in traffic flow, decreases in the travel-time rate (i.e., increases in travel speeds) usually result in reduced rates of fuel consumption. It should be noted that this relationship differs substantially from that between travel speeds and fuel-consumption rates under free-flow conditions. It is estimated that contra-flow operations (i.e., increases in operating speeds) would reduce fuel-consumption rates for buses by 11 percent during the AM peak and 6 percent during the PM peak. It has been assumed, as in the 1980 CTPS study, that the contra-flow lane would not have a significant effect on travel speeds in the general-traffic lanes.

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[1] Ramp metering on the expressway is discussed in greater detail in Section 3.2.

[2] Fred Wagner, Urban Transportation Energy Conservation Analysis of Traffic Engineering Actions, prepared for U. S. Department of Energy, October, 1979, pp. 27-28.

The results of the analysis are summarized in Table 2-2. Operation of a contra-flow lane during the AM peak only is estimated to yield a reduction in fuel consumption of approximately 200-400 gallons per day, or 50,000-100,000 gallons per year; morning and afternoon contra-flow operations combined would yield a savings of roughly 320-640 gallons per day, or 80,000-160,000 gallons per year.

It should be noted that these estimates do not reflect an allowance for additional VMT which may be generated by vehicles which are "left at home" as a result of increased peak-period transit usage. To adjust for additional non-work travel induced by the increased availability of autos at home, the estimated net reduction in VMT and energy consumption should be reduced by 8 percent.

- Priority Ramp-Bypass

The 1980 CTPS study recommended that ramp metering be implemented at the Neponset and Columbia northbound on-ramps (these were the only ramps at which metering was considered). The energy-conservation impacts of an HOV priority bypass treatment at the Neponset ramp are analyzed below. Bypass treatments are possible only at Neponset, since there is only one lane on other ramps. However, the construction of exclusive HOV ramps at other locations, which would have effects similar in nature to bypass lanes, remains at least a theoretical possibility. Since traffic volumes are highest on the Neponset ramp, the impacts projected in the following analysis represent the maximum which can be achieved with any single ramp bypass or exclusive-ramp treatment implemented in conjunction with ramp metering.

Peak-period (6:30-9:30) AM traffic volumes on the Neponset ramp are estimated to be 11,600 vehicles,[1] most of which are automobiles. It is estimated that two-passenger carpools presently constitute 19 percent, and three-or-more-passenger carpools 5 percent, of the ramp's total volume of traffic, assuming that the carpool mode shares on the ramp equal those which have been documented for portions of the expressway itself north of Furnace Brook.

The standard minimum travel-time savings suggested as a prerequisite for implementing priority ramp-bypass treatments is one minute. Forecasting the actual travel-time savings which can be achieved with specific ramp-metering and priority-bypass

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[1]The 1980 CTPS study reports peak hour volumes of 4,290 vehicles. Assuming the same relationship between peak-hour and peak-period volumes as on the expressway itself, peak-hour ramp volumes have been multiplied by a factor of 2.7.

TABLE 2-2

Southeast Expressway: Projected Impacts of Contra-flow Lane

	Existing Traffic Lanes (AM Peak Period)	AM-Peak-Period Contra-flow (Northbound)	AM (Northbound) and PM (Southbound) Contra-flow
Auto Traffic	19,400* (1977)	19,000-19,200	19,075
Bus Ridership	3,400* (1977)	3,800-4,200	4,050
Number of Buses	100* (1977)	130	124
Avg. Speed of General Traffic	34 mph* (1977)	34 mph*	34 mph (AM) 40 mph (PM)
Avg. Bus Speed	34 mph (AM)* (1977) 40 mph (PM)	50 mph	50 mph (AM) 50 mph (PM)
Changes in Peak-Period Consumption	--	200-400 gal./day; 50,000-100,000 gal./year	320-640 gal./day; 80,000-160,000 gal./year
Net Change in Total Energy Consumption		46,000-92,000 gal./year	74,000-148,000 gal./year

*From CTPS Technical Report 20, Southeast Expressway Lane Allocation Study, August, 1980.

applications is beyond the scope of this report. The following analysis of bypass-related energy impacts is therefore based on the range of travel-time-savings values which appears plausible, on the basis of existing conditions at the Neponset ramp, as well as ramp-metering experiences in other metropolitan areas.

The predicted impact of travel time changes in the range of one to three minutes, if the priority lane were open to carpools of two or more passengers, would be an increase in the use of carpools by 50-140 persons per day, and a decline in the use of single-occupant automobiles of 30-75 vehicles per day.

Impacts on fuel consumption would be as follows:

- one-minute decline in travel times: reduction of 35 gallons/day, 8,800 gallons/year
- three-minute decline in travel times: reduction of 90 gallons/day, 22,000 gallons/year

The results of this analysis are presented in Table 2-3.

It should be noted that these estimates do not reflect the potentially adverse effects on fuel economy associated with increased ramp delays for non-priority vehicles. It is also assumed that virtually all new carpools will be composed of former single-occupant-auto users (as opposed to current transit riders, for example). While these figures may therefore overstate the reduction in fuel consumption based on 1977 traffic volumes, the 13-percent rise in expressway traffic which has occurred since that time would probably tend to offset the impact of the above factors.

If a bypass lane were restricted to carpools of three or more passengers only, the forecasted mode shift would not exceed 35 vehicles per day, yielding a maximum reduction in fuel consumption of roughly 40 gallons per day, or 10,000 gallons per year. The above estimates do not account for the quantities of fuel that may potentially be consumed by vehicles "left at home." As noted earlier, a reasonable estimate of this effect would be a reduction in the above projected fuel-consumption savings of 8 percent.

2.3 Route 3: Exclusive HOV Lane

Route 3 is a controlled-access highway extending from the Sagamore rotary in Bourne on the south to the junction of Route 128 and the Southeast Expressway on the north. Like the Southeast Expressway, Route 3 carries heavy volumes of both commuter and seasonal recreational traffic between the Boston metropolitan area and the South Shore. Route 3 is also similar to the expressway in that it experiences high levels of traffic congestion over its northern, urbanized segment.

TABLE 2-3

Southeast Expressway: Projected Impacts of Priority Bypass Lane at Neponset Ramp

	Existing Conditions	Priority Bypass Lane			
		2+ Passengers		3+ Passengers	
		3-Minute Travel-Time Savings	1-Minute Travel-Time Savings	3-Minute Travel-Time Savings	1-Minute Travel-Time Savings
Number of Vehicles					
• 1 Passenger	8,820	8,680	8,770	8,780	8,815
• 2 Passenger	2,200	2,245	2,220	2,185	2,175
• 3+ Passengers	580	600	580	600	590
Total	11,600	11,525	11,570	11,565	11,580
Number of Passengers					
• 1 Passenger	8,820	8,680	8,770	8,780	8,815
• 2 Passengers	4,400	4,490	4,440	4,370	4,380
• 3+ Passengers	1,740	1,800	1,750	1,810	1,765
Total	14,960	14,960	14,960	14,960	14,960
Decrease in Peak-Period Fuel Consumption		88 gal./day	35 gal./day	40 gal./day	--
Net Decrease in Total Energy Consumption		22,000 gal./year	8,800 gal./year	10,000 gal./year	--
(all time periods and trip purposes)		20,200 gal./year	8,100 gal./year	9,200 gal./year	--

A 1977 study of the Route 3 corridor by the Old Colony Planning Council recommended that a lane be added to Route 3, extending from the Route 139 interchange in Pembroke to Route 18 in Weymouth.[1] This lane, to be located either adjacent to the existing roadway or within the roadway median, would provide preferential treatment for high-occupancy vehicles. The study specifically considered designating the added lane for the exclusive use of high-occupancy vehicles during peak periods.

The construction of a new lane for the exclusive use of HOVs represents a variation of the busway concept, which differs from the reserved-lane treatments considered for the Southeast Expressway and I-93. A project of this type would require a substantial capital investment, as well as a significantly longer period of time for development and implementation. However, the potential energy-conservation impacts associated with an exclusive HOV lane may also substantially exceed those of more limited reserved-lane treatments. This is illustrated by the following analysis results, which reveal fuel-consumption impacts far greater than those estimated for a Southeast Expressway contraflow lane.

Traffic Impacts

It has been assumed that a reversible exclusive HOV lane added to Route 3 would increase travel speeds from approximately 38 mph to 50 mph in the AM peak period, which is consistent with percentage increases in speed estimated in the Old Colony report cited earlier. The average trip distance on the new HOV lane is assumed to be nine miles, which yields a travel-time savings of roughly 3.5 minutes per trip, relative to existing travel conditions. PM travel savings are assumed to be somewhat less, as on the expressway, yielding round-trip travel-time savings of 6.25 minutes. The resulting impact is a decline of approximately 1200 vehicle-trips per day,[2] at an average round-trip distance (both on and off Route 3) of 36 miles, for a reduction of 43,200 VMT per day. Increased rates of carpool formation account for most of the decline in VMT.

The modal shift is shown in Table 2-4. The estimated decline in vehicle-trips is apt to be overstated, since this analysis presumes that the increased use of buses and carpools will result entirely from the reduction in single-occupant-auto use, rather than a diversion of current Red Line riders or the generation of new trips.

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[1] Old Colony Planning Council, Route 3 Corridor Study, 1977.

[2] Travel-time elasticity is assumed to be -1.1, which is consistent with the Southeast Expressway contra-flow analysis. It should be noted that this value is the greatest of the range for "large multinucleated cities" (-.46 to -1.10) reported by Y. Chan and F. L. Ou in "A Tabulation of Demand Elasticities for Urban Travel Forecasting."

TABLE 2-4

Route 3: Projected Impact of Exclusive HOV Lane

	Estimated 1985 Base Case	HOV
Number of Vehicles		
• 1 Passenger	11,990	10,110
• 2 Passengers	3,240	3,730
• 3+ Passengers	970	1,120
• Bus	109	126
Number of Passengers		
• 1 Passenger	11,990	10,110
• 2 Passengers	6,480	7,470
• 3+ Passengers	2,910	3,350
• Bus	2,950	3,400
Average Bus Speed	38 mph	50 mph
Reduction in Peak-Period Fuel Consumption	-	2,800 gal./day 700,000 gal./year
Net Reduction in Total Fuel Consumption	-	2,600 gal./day 644,000 gal./year

Fuel-Consumption Impacts

The fuel-consumption impact associated with the Route 3 exclusive HOV lane would be a reduction of 2800 gallons per day, or 700,000 gallons per year, during peak periods. Allowing for increases in off-peak or non-work trips, the estimated savings would equal 2,600 gallons per day, or 644,000 gallons per year. As noted previously, this estimate may overstate actual VMT-related energy savings: the actual impact should be considered as ranging between 1,300 and 2,600 gallons per day, or 422,000-644,000 gallons per year.

The above estimates reflect calculations not only of VMT-related energy impacts, but also the effects of increased travel speeds on the rate of fuel consumption. Specifically, it is estimated that an increase from approximately 38 mph to 50 mph will reduce the fuel-consumption rate by seven percent.

As stated earlier, fuel-consumption impacts are far in excess of those estimated for a Southeast Expressway contra-flow lane. This difference results from two major factors:

1) The average VMT savings per one-way vehicle-trip eliminated is assumed to be 18 miles in the case of the Route 3 HOV lane versus 12 miles for the Southeast Expressway contra-flow lane.

2) The Route 3 HOV lane would be open to carpools as well as buses, while the Southeast Expressway contra-flow would be limited to buses only.

It should be noted that a substantial expenditure of energy would be required during the process of constructing a Route 3 contra-flow lane. This one-time-only energy cost should be considered in any detailed evaluation of this project which may be undertaken in the future.

2.4 Route 1A/McClellan Highway: Reserved HOV Lane

The segment of Route 1A designated as the McClellan Highway is a major access road connecting North Shore communities with downtown Boston. The McClellan Highway terminates at the east portal to the Sumner Tunnel, and experiences intense congestion over a section of approximately one-half mile between the airport off-ramp and the tunnel portal. The queues experienced on the McClellan Highway originate as far upstream as the southbound Central Artery entrance ramp, particularly during the PM peak period (3:30-5:30), although the tunnel itself is more often the bottleneck during the AM peak (7:30-9:00).

A reserved-lane treatment could be applied on the congested section of the McClellan Highway which would allow high-occupancy vehicles to bypass the short, but extremely slow-moving queue

which precedes entry to the Sumner Tunnel. This section of the queue has a maximum length of approximately .5 miles in the AM peak and of approximately .8 miles in the PM peak. To bypass the queue would require the creation of a reserved lane of at least 1.7 miles,[1] although the total delay in travel time to non-priority vehicles would remain unchanged, due to an increase in queue speed from approximately 5 to approximately 17 mph. Travel time for priority vehicles would decline on average by approximately four minutes in the AM and five minutes in the PM.

Traffic and Energy Impacts

One potentially significant problem which bears further investigation is the effect of the lane on traffic exiting the traffic stream to the airport off-ramps. If the left lane were selected for exclusive HOV use, traffic entering onto the ramp from the McClellan Highway would conflict with the reserved lane. The right lane would therefore probably be a better choice for an HOV lane. Traffic from Havre Street, just before the toll booths, would be channeled to the right of the lane on Porter Street and to the toll booths (see Figure 2-1). There would also be a need for enforcement of the reserved-lane restrictions in the area which precedes entry to the toll booths. Single-occupant vehicles illegally using the reserved lane could be directed away from the toll booths, forcing them to continue northward.

The impacts of the reserved lane on modal shares and fuel consumption are shown in Table 2-5. If the reserved lane were open to carpools with two or more passengers, there would be a total increase of approximately 75 carpools and 50-80 bus passengers in the morning and evening peak periods, yielding a net decline of approximately 250 one-way vehicle-trips per day on the highway. If the reserved lane were restricted to carpools of three or more occupants, there would be a total increase of roughly only 10 carpool trips in the AM and PM peak periods, and a net decline of 120-150 vehicle-trips per day on the highway.

Changes in peak-period fuel consumption would equal approximately 350 gallons per day and 87,500 gallons per year for a two-or-more-occupant carpool lane, and 270 gallons per day or 67,500 gallons per year for a three-or-more-occupant carpool lane. These figures reflect both the decline in VMT and the increases in travel speeds which would result from operation of the reserved lane. Allowing for increased off-peak VMT by vehicles "left at home," fuel-consumption savings are estimated to equal 320 gallons per day or 80,500 gallons per year for a two-or-more-occupant reserved lane, and 250 gallons per day or 62,000 gallons per year for a three-or-more-occupant lane.

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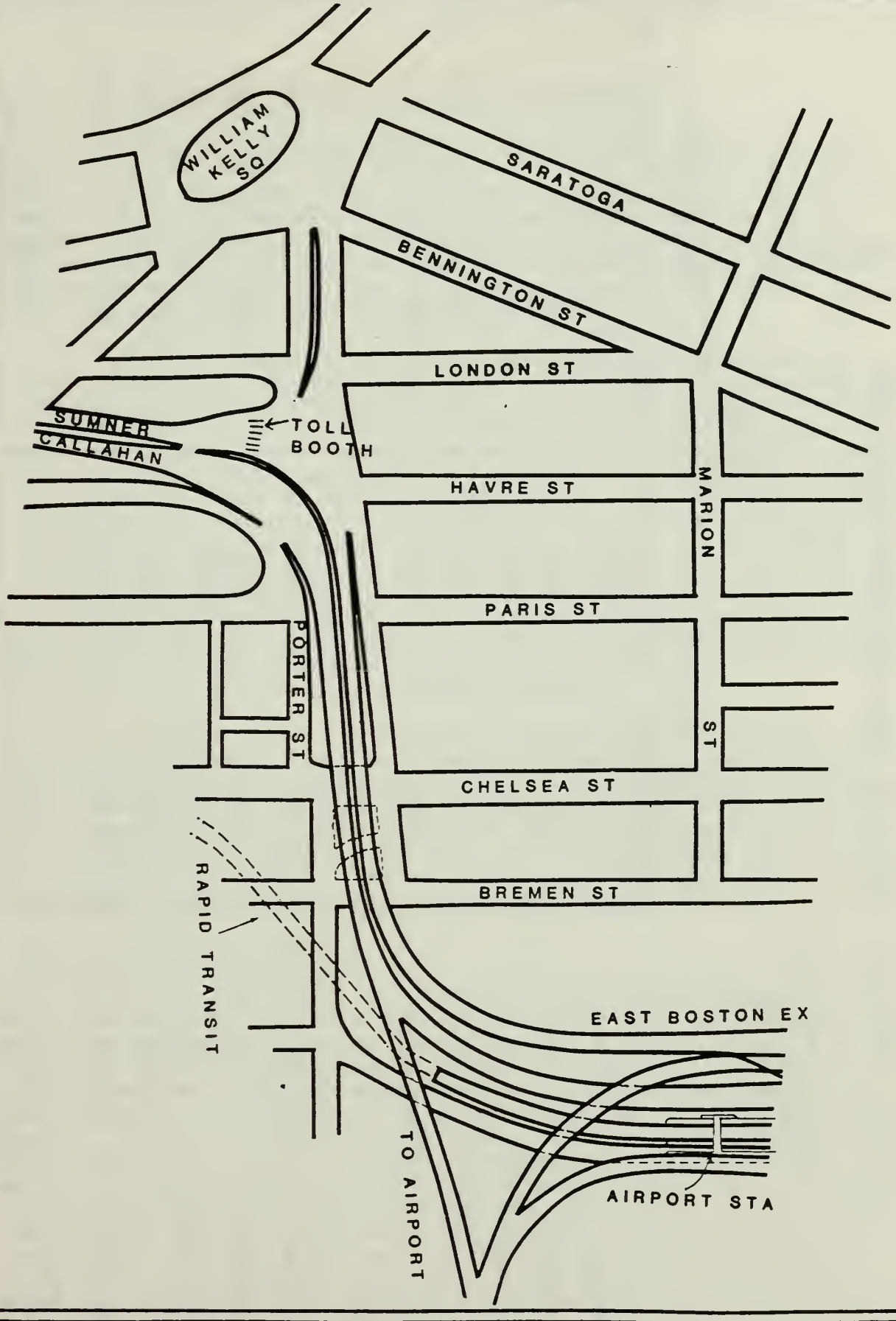
[1]Corresponding to average maximum-AM-queue length.



McCLELLAN HIGHWAY - ENTRY TO SUMNER TUNNEL

Figure 2-1

TABLE 2-5

Route 1A: Projected Impact of Reserved HOV Lanes

	Estimated Existing Conditions (7:00-9:00 AM; 3:30-5:30 PM)	HOV Lane			
		2+ Passenger		3+ Passengers	
Number of Vehicles (one-way)		7:00-9:00 AM	3:30-5:30 PM	7:00-9:00 AM	3:30-5:30 PM
• 1 Passenger	7,000	6,800	6,780	6,950	6,920
• 2 Passengers	750	825	835	740	730
• 3+ Passengers	170	170	170	177	180
• Bus	40	41	42	41	42
Total	7,960	7,836	7,827	7,901	7,872
Passengers (one-way)					
• 1 Passenger	7,000	6,800	6,780	6,950	6,920
• 2 Passengers	1,500	1,650	1,670	1,480	1,465
• 3+ Passengers	500	500	500	520	535
• Bus	1,200	1,250	1,280	1,250	1,280
Average HOV Speed	3 mph	50 mph	50 mph	50 mph	50 mph
Change in Peak-Period Fuel Consumption	--	350 gal./day 87,500 gal./year		270 gal./day 67,500 gal./year	

2.5 Massachusetts Turnpike: Reserved HOV Lane

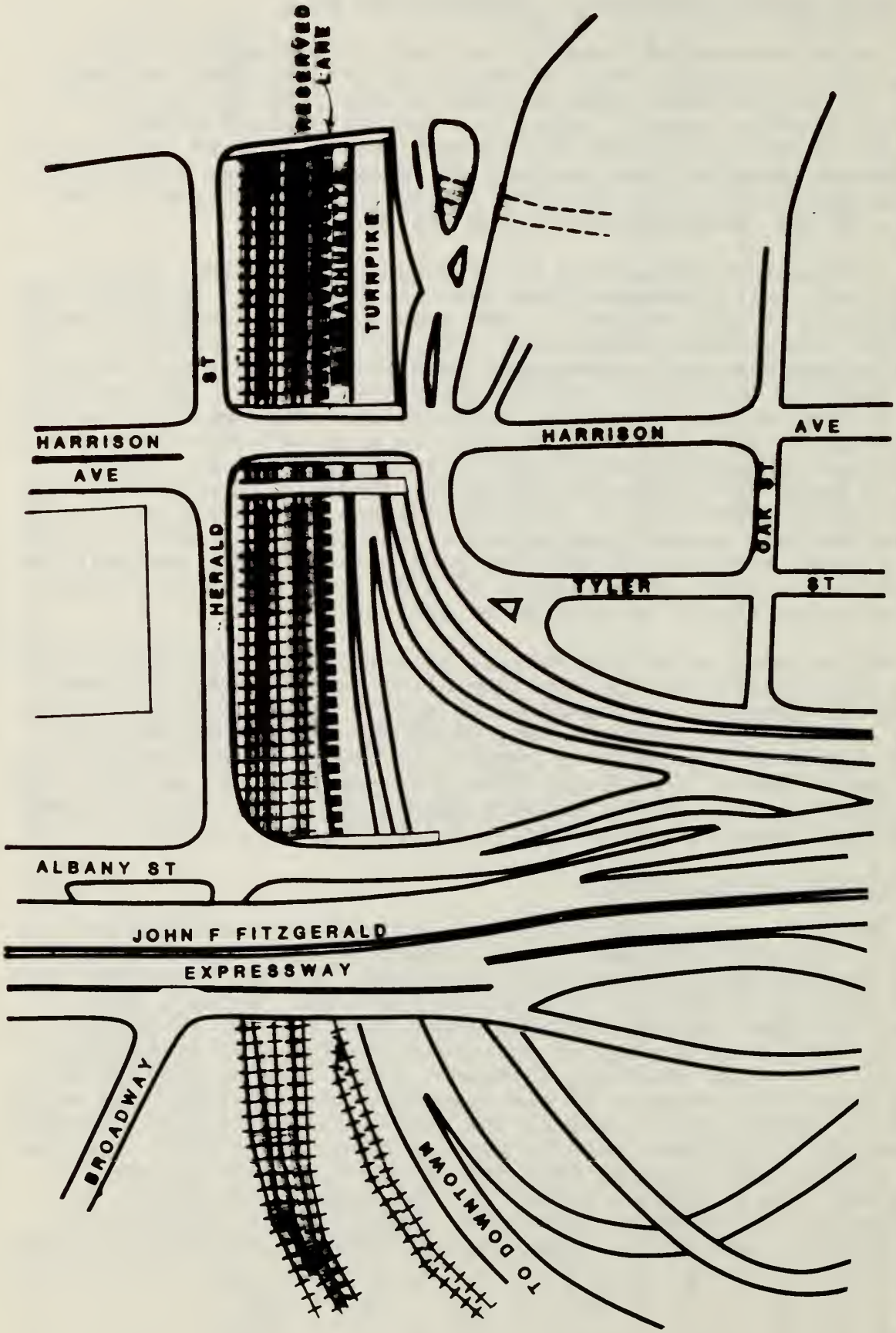
The Massachusetts Turnpike is a principal commuter route connecting the suburbs west of Boston to the Back Bay and downtown. While the Mass. Pike provides a high level of service to commuter traffic overall, there are regularly short delays between the Prudential and Beacon Park exits, in both the morning and evening peak periods, as well as somewhat longer delays in the eastbound direction from the Copley Square off-ramp to the Artery Bridge, particularly during the PM.

The maximum peak-period delay between the Prudential and Beacon Park exits averages less than one minute. A reserved lane operating over this segment of the highway would therefore result in small travel-time savings for HOVs, as well as negligible modal shifts and fuel-consumption impacts. An eastbound reserved lane from the Prudential exit to the Central Artery ramp would have greater energy-conservation potential. The specific measure considered in the following analysis is a concurrent-flow eastbound lane of approximately 1.25 miles, located in the right traffic lane. The reserved provisions would be in effect during the PM peak. Operation of the lane during the AM peak is likely to have minimal energy impacts due to the shorter duration of the delays experienced in the morning peak period. This analysis is therefore confined to evaluation of a PM reserved lane, although AM operations should be considered optional.

As has been noted previously, concurrent-flow reserved lanes which are created through the removal of general traffic lanes are apt to generate controversy and public opposition. In this case, however, the reserved-lane treatment under consideration would occupy an even shorter segment of the highway than does the "queue-jumper" concurrent-flow preferential lane on I-93, and may therefore meet with a greater degree of general public acceptance than larger-scale projects of this nature.

Traffic and Energy Impacts

The queue preceding the Central Artery entrance ramp is short in terms of distance (i.e., generally less than one-half mile) but extremely slow-moving, at 4 mph. An exclusive HOV lane could be created between Exit 22 and the Artery Bridge, just before the last turnpike exit diverges into the two ramps which lead either to the Artery or the South Station area of downtown Boston. For HOVs traveling downtown, which include all the MBTA buses using this section of the turnpike, the reserved lane would serve to bypass most or all of the Artery-related queue, without generating significant traffic weaving (see Figure 2-2). In the case of the HOVs entering onto the Artery-from the turnpike, there would be a need to merge with the general traffic at the point where the reserved lane ends. Non-priority traffic not entering onto the Artery would need to merge to the right at this



CONFIGURATION OF POSSIBLE RESERVED LANE ON THE MASSACHUSETTS TURNPIKE

Figure 2-2

point into the HOV traffic stream. The impacts of these movements on traffic flow should be given more detailed analysis. One further problem is that the reserved lane would impede access to the breakdown lane for non-priority vehicles.

Travel-time savings for priority vehicles would average somewhat less than four minutes. The impacts of the reserved-lane treatment on modal shares and fuel consumption are shown in Table 2-6. If the reserved lane were limited to buses and carpools with three or more passengers, the result would be a small modal shift and fuel-consumption savings of less than 50 gallons per day. The primary reason for the small magnitude of these impacts is that the reserved lane would operate in the off-peak direction for bus riders. The principal beneficiaries of the preferential treatment would thus be carpool users. If the reserved lane were open to carpools of two or more occupants, the impact on modal shares and energy consumption would increase. A decline of over 100 vehicle-trips per day would result, as well as a reduction in fuel consumption of 150 gallons per day during peak periods. This is equivalent to an annual peak-period savings of 37,500 gallons per year, or 34,500 gallons per year allowing for increased off-peak non-work travel. These relatively modest energy savings should be weighed against the potential traffic-related problems which may be associated with the lane's operation.

2.6 Priority Signal Treatments

A priority bus signal program was recently evaluated as part of the Boston Traffic Control System. The BTCS, which is now nearly complete, will provide for computerization of traffic controls throughout the City of Boston. In designing the system, a list was developed of 14 bus-route sections which meet the bus-volume standards (10-20 vehicles per hour) recommended for preferential-signalization treatments. This list is shown in Table 2-7.

The list of route sections considered as candidates for priority treatments was reduced to three, as a result of an added requirement that they contain five or more intersections. It was further judged that bus and trolley densities on the first route section included on the list, consisting of Cambridge St., Brighton Ave., and Commonwealth Ave. between Gordon St. and Kenmore Square, exceeded the range suited to priority signalization. There were then only two route sections remaining as candidates for priority signal treatments:

- Massachusetts Avenue between Beacon and Melnea Cass
- Tremont Street between Stuart and Park

These two sections comprise a total of 26 intersections.

The priority signal concept was finally rejected entirely for the BTCS, as it was determined that the technology used in

TABLE 2-6

Massachusetts Turnpike: Projected Impact of 0.7-Mile Reserved Lane

	Estimated Existing Conditions (4:00-6:00 PM)	HOV Lane	
		2 Passengers	3+ Passengers
Number of Vehicles (one-way)			
• 1 Passenger	4,600	4,375	4,535
• 2 Passengers	1,250	1,340	1,250
• 3+ Passengers	300	300	320
• Bus	65	65	65
Total	6,200	6,080	6,170
Number of Passengers (one-way)			
• 1 Passenger	4,600	4,375	4,535
• 2 Passengers	2,500	2,675	2,500
• 3+ Passengers	900	900	965
• Bus	600	650	650
Average HOV Speed	4 mph	50 mph	50 mph
Reduction in Peak-Period Fuel Consumption		150 gal./day 37,500 gal./day	35 gal./day 8,750 gal./day

Boston Traffic Control System: Candidate Sections for Bus Priority

Bus-Route Section	No. of Signals	Buses per Hour, each Direction	Distance ft.
Cambridge, Brighton and Commonwealth - Gordon to Kenmore Square	18	15*	12,000
Massachusetts Ave. - Beacon to Melnea Cass	18	12	8,000
Tremont - Stuart to Park	8	18	2,100
Broadway & Herald - Dorchester to Washington	4	13	2,300
Brookline - Longwood to Park Drive	4	11	2,000
Summer - High to Dorchester	4	17	1,300
N. Washington - Chardon to Causeway	3	20	1,200
Boylston - Exeter to Clarendon	3	11	1,200
Tremont - Berkeley to Charles South	3	11**	1,000
Dudley or Warren	2 or 3	14 or 16	200 or 400
Columbus - Centre to Heath	2	11	750
St. James - Dartmouth to Clarendon	2	11	600
Dartmouth - Boylston to St. James	2	10	300
Tremont - Whittier to Ruggles	2	12	300

*23 bph for 1400 ft. on Brighton between Cambridge and Harvard; 30 buses and trolleys over 7800 ft. on Commonwealth.
**Southbound only; northbound is 6 bph.

Source: BTCS Study

signal-preemption systems was inappropriate for Boston-area applications. Specifically, a review of the available technology revealed that the systems in use were all "active," meaning that all the buses to benefit from signal preemption would need to be equipped with signal-emitting devices. Since the MBTA does not assign specific buses to individual routes, all buses operating from garages serving the priority bus routes would have been required to carry signal devices, which was judged to be impractical.

It should be noted, however, that "passive" systems, which do not require buses to carry special equipment, have in fact been used in both Washington, D.C. and Minneapolis. These systems incorporated the use of pavement loops which could detect the presence of preselected bus types. In both cities, use of the systems was discontinued after approximately one year, although this was not due to any problems related to the detection technology. The passive preemption system detected the priority buses 92 to 100 percent of the time, and false classifications of trucks and other large vehicles as buses occurred less than one percent of the time.

Most of the bus-route sections in the Boston metropolitan area which are suited to priority-signal treatments are located in the City of Boston, and are therefore included in the BTCS list shown in Table 2-7. Some additional locations where bus-volume concentrations may be sufficient to justify signal preemption would be in the vicinity of rapid transit stations. Bus-route segments which feed into the following stations, in particular, are potential candidates for priority-signal treatments:

- Sullivan Square
- Malden Center
- Oak Grove
- Harvard Square
- Central Square
- Cleveland Circle
- Alewife[1]

Two other candidate route segments would be Broadway and Highland Avenue in Somerville. More detailed analysis is required to determine whether the volumes of buses and number of signals at these nine locations is in fact sufficient to warrant signal preemption. It should also be noted that it would be necessary to provide short reserved bus lanes preceding the intersections with priority signal controls.

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[1]Expected date of station opening: March, 1985

If route segments with ten or more buses per hour and four or more signals (rather than the five or more signals required in the BTCS analysis) are considered for priority-signal treatments, the first six locations listed in Table 2-7 would qualify. For the purposes of this analysis, it will be assumed that half of the candidate areas outside the City of Boston which are identified above would also provide priority-signal opportunities. This is, in total, a relatively small number of prospective applications, and the energy-conservation potential is therefore modest.

Estimates of potential travel-time savings and ridership impacts for the six candidate route sections in the City of Boston are shown in Table 2-8. It is estimated that there would be a decline of approximately 650 vehicle trips per day as a result of the signalization program in the City of Boston, and a reduction of roughly 150 vehicle trips per day in other parts of the metropolitan area, resulting from signal treatments implemented at other locations. Assuming an average one way trip distance of 3 miles, the reduction in vehicle trips would produce savings of 4,800 VMT per day, which yields a reduction in fuel consumption of approximately 250 gallons per day.

Bus fuel economy would also increase significantly as a consequence of eliminating traffic signal stops and starts. This factor could result in an additional fuel consumption savings of 100-150 gallons per day, yielding a total reduction in fuel consumption of 350-400 gallons per day, or 87,500-100,000 gallons per year.

TABLE 2-8

Estimated Impacts of Priority-Signal Treatments in City of Boston

Bus-Route Section	Travel-Time Savings	AM and PM Peak-Period Ridership	Increase in Ridership*	Reduction in Auto Use**
Cambridge, Brighton and Commonwealth - Gordon to Kenmore Square	12 min.	1200	300	250
Massachusetts Avenue - Beacon to Melnea Cass	12 min.	1000	200	150
Tremont - Stuart to Park	6 min.	1400	200	150
Broadway & Herald - Dorchester to Washington	3 min.	1000	40	30
Brookline - Longwood to Park Drive	3 min.	900	40	30
Summer - High to Dorchester	3 min.	1400	50	40

*Assumed travel-time elasticity of -0.8.
**Figures in this column represent 80%.

3.0 MEASURES TO IMPROVE TOTAL VEHICULAR FLOW

BACKGROUND: TYPES OF ACTIONS

Traffic-flow-improvement measures are intended to reduce highway congestion and improve vehicle travel times. These measures expand the effective capacity of highway facilities by increasing their operating efficiency. Projects of this type usually require relatively low levels of capital investment, since the improvements consist primarily of operational changes and, sometimes, minor modifications of facility design. The range of traffic-flow improvements with potential energy impacts may be classified by type into a number of categories, as shown in Table 3-1. The measures within each of these categories are briefly described below.

Intersection-Design Modifications

Intersections generally represent the critical constraint on the capacity of an arterial street system. The focus of a number of traffic-flow-improvement measures is therefore the street intersection. The most effective means by which intersection capacity can be increased is often the addition of left-turn lanes, which can substantially reduce intersection delays. In situations where there are substantial volumes of right-turning vehicles, the provision of right-turn lanes may also reduce through-traffic delays, although not generally to the same extent as left-turn lanes in corresponding situations.

Turning lanes may sometimes be created without any physical expansion of the intersection, e.g., through narrowing existing lanes or removing on-street parking. In other cases it is necessary to widen the intersection through construction. While this may require a relatively substantial capital investment compared to other types of traffic-flow improvements, in many areas the expense is moderate from a benefit/cost perspective. In areas where there is adjacent development, however, the expense of intersection widening can be prohibitive.[1]

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[1]Neilon J. Rowan, Donald L. Woods, and Vergil G. Stover, Alternatives for Improving Urban Transportation, A Management Overview, prepared for the Federal Highway Administation, October 1977, p. 12-2.

TABLE 3-1

Traffic-Flow-Improvement Measures

Intersection-Design Modifications

- intersection widening
- addition of left- and right-turn lanes
- correction of off-sets

Intersection-Operation Patterns

- prohibited left turn*
- relocation of bus stops*
- protected left turns*

Major Flow Patterns

- one-way streets*
- reversible flow*

Traffic-Signal Improvements

- optimization and coordination of signal systems
- computerization

Freeway-Access Control

- surveillance
- driver advisories
- ramp metering

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*From Alternatives for Improving Urban Transportation: A Management Overview, FHWA, 1977, page 12-4.

Intersection-Operation Patterns

The primary focus in this category of traffic-flow improvements is once again on left-turns at intersections. In situations where it is infeasible to add exclusive left-turn lanes, the prohibition of left-turns or the protection of left turns through special signal cycles are possible options for improving traffic flow at intersections. The prohibition of left-turns is often a highly effective means of reducing travel time for the through-traffic stream; however, this may result in substantial lengthening of travel times and distances for left-turning vehicles forced to select alternate routes. The impacts of protected left turns have been variable, generally producing at best small reductions in overall vehicle delays and travel times.[1]

The relocation of bus stops in downtown areas can also often result in significant reductions in the delays experienced by turning vehicles. Impacts outside of the CBD, however, tend to be negligible.[2]

Major Flow Patterns

One-way streets are currently in effect in most cities where they are appropriate. It has been demonstrated that the restriction of traffic flow to a single direction can in many cases substantially increase roadway capacity, producing travel savings ranging from 20 to 40 percent.[3]

Reversible lanes may be implemented on two-way streets to expand the capacity of these facilities to accommodate peak-direction traffic flows. Traffic-flow reversal can be designated through signal adjustments or the placement of cones. Both signal installation and the daily moving of cones can be quite costly, relative to potential benefits. It has been found that travel-time savings associated with reversible-lane operations tend to range from 20 to 50 percent over the street segments directly affected.[4]

Traffic-Signal Improvements

Adjustment of traffic-signal timing represents one of the most practical and effective means of improving intersection traffic flow. The FHWA estimates that vehicles stopping and

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[1]Ibid., pp. 12-4 - 12-6.
[2]Ibid.
[3]Ibid.
[4]Ibid.

idling due to poor signal timing can account for 40 percent of vehicle fuel consumption in individual street networks.[1] Fuel conservation is therefore one of the principal motivations underlying the FHWA's current nationwide effort to promote optimization of traffic-signal timing. Beginning in 1982, the FHWA embarked on a program to provide technical assistance to cities and states in the development of signal-timing plans. It is the goal of this effort "to support optimization of all the coordinated signals in the United States" within a period of four consecutive years.[2]

Adjustment of traffic signals may involve either of the following:

- timing to provide for signal progressions in the direction of heavy traffic
- operation of traffic signals in a mode which is traffic-responsive; i.e., allowing the signal cycle to change based on traffic flows[3]

Coordination of multiple signals is necessary to optimize the traffic-flow improvement and energy-conservation potential of signal-timing adjustments. It has been estimated that system-wide coordination of signal timing can reduce the number of involuntary vehicle stops by 40 percent.[4]

The process of optimizing signal systems can be performed by computer, and the FHWA has sponsored the refinement of a software package which can be used for this purpose. The package has been applied in eleven U. S. cities as part of the FHWA's National Signal Timing Optimization Project. The findings of this project include the following estimates of annual impacts per average intersection analyzed:

- 15,470 vehicle-hours saved
- 455,921 vehicle-stops eliminated
- 10,524 gallons of fuel saved

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[1]Federal Highway Administration, Office of Traffic Operations, and University of Florida, Transportation Research Center, National Signal Timing Optimization Project: Summary Evaluation Report, May 1982, p. 1.
[2]Ibid.
[3]Alan M. Voorhees and Associates, Inc., Guidelines to Reduce Energy Consumption Through Transportation Actions, prepared for the Urban Mass Transportation Administration, May 1982, p. A-7.
[4]Rowan, et al., Alternatives for Improving Urban Transportation, p. 12-8.
[5]FHWA, National Signal Timing Optimization Project, p. 5.

Computerized control of traffic signals, as opposed to a one-time or periodic computer calibration, allows for the optimization of system operations on a continuing basis. A computerized control system can be responsive to changing traffic conditions, which permits optimal operating conditions to be attained more frequently than would otherwise be possible.

Freeway Access and Control

Measures included in this category are designed to reduce freeway congestion by controlling the volumes of traffic entering limited-access facilities. Actions to control freeway access tend to be complementary to one another. In particular, freeway-surveillance techniques, which identify the location of freeway delays, provide information which is necessary as a basis for driver-advisory displays and useful for setting ramp-meter timings.

While some combination of freeway surveillance, ramp metering, and driver advisories can often be effective in reducing freeway congestion, energy savings tend to be highly variable and often relatively small. Any energy savings realized as a result of improved highway-traffic flow must be weighed against additional energy consumed by vehicles diverted to alternate routes or stopped and idled at metered access ramps.

Impact of Traffic-Flow Improvements on Energy Consumption

The traffic-flow-improvement measures described above are commonly implemented for the purposes of increasing facility capacity, reducing travel times, and improving safety. Fuel-consumption savings are often viewed as a possible byproduct of upgrading the quality of service on a highway facility. Reductions in the frequency of stops and the total amount of vehicle-delay time, which are reflected in higher operating speeds, result in improved fuel economy. Usually, however, it is the attainment of higher operating speeds, irrespective of any associated impacts on fuel consumption, which is the primary objective.

Potential energy-conservation impacts of traffic-flow improvements have generally not been emphasized, in part, because of concerns relative to the ultimate effect of these measures on VMT levels. It is known that improved highway-operating speeds, which result in reduced travel times, will encourage some degree of additional auto travel. In the case of work trips, increased auto VMT is likely to occur as a result of a mode shift away from transit, while additional non-work auto travel will arise from an increase in both the frequency and length of auto trips. Thus, any energy savings associated with improved fuel economy must be weighed against potential increases in fuel consumption due to induced increases in auto travel.

In a 1978 study, the effects of traffic-flow improvements on energy consumption were estimated by analyzing the impacts of changes in travel time (and operating speed) on both VMT levels and fuel-consumption rates.[1] The study concluded that in the short- or intermediate-term future, traffic-flow improvements would yield significant energy savings. Specifically, it was estimated that a one-percent decrease in travel time would result in a reduction in fuel consumption of 0.25 to 0.50 percent. It was estimated that in the longer-range future, however, as individuals became able to make greater adjustments in their travel patterns, the net impact of traffic-flow improvements would likely be a small increase in fuel consumption.

These results lend support to the view that the energy-conservation potential associated with traffic-flow improvements is generally poor, at least in the long term. However, any increases in fuel consumption resulting from these measures are apt to be small in magnitude. Potential benefits, in terms of improved travel times, may therefore outweigh any adverse energy impacts related to traffic-flow improvements. Moreover, the possibility remains that individual highway projects may, under the right circumstances, produce beneficial energy impacts. Potential projects therefore warrant analysis on an individual basis to determine their net effects on fuel consumption.

POTENTIAL APPLICATIONS IN THE BOSTON AREA

3.1 Projects Included in the Transportation Improvement Program

The potential applications of traffic-flow-improvement measures are numerous. Table 3-2 presents the projects currently included in the region's Transportation Improvement Program (TIP) which are classified as traffic or signalization improvements. These consist primarily of channelization and intersection-redesign projects, and of signal-timing changes. The projects included in the TIP have been reviewed and accepted by the MDPW as candidates for federal funding and represent only a fraction of the possible traffic-flow-improvement applications in the region. Projects listed in the Annual Element are expected to be ready for implementation during fiscal year 1984. The vast majority of the projects listed in Table 3-2 are contained in the 2-5-Year Element, which means that they should be ready for implementation during the fiscal years 1985-1988. While the inclusion of a project in the TIP does not represent a commitment of funds, the TIP does reflect the region's current funding priorities.

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[1] Fred Wagner, Urban Transportation Energy Conservation, Analysis of Traffic Engineering Actions, prepared for U. S. Department of Energy, October 1979, pp. 26-31.

TABLE 3-2(a)

Transportation Improvement Program 1984-1988
Traffic and Signal-Improvement Projects[1]

Municipality	Project
Revere	traffic signals and left-turn storage
Sudbury	Route 20 (widening, channelization, signals)
Boston	conversion of 48 pedestrian signals to comply with codes
Boston	centralized computer traffic-control system at approximately 200 locations in Boston
Arlington	intersection improvements
Ashland	intersection improvements
Bedford	widening to provide a turn lane
Brookline	five (5) locations on Route 9: widening, signals, resurfacing
Brookline	Cypress Street at Kendall Street (signals, traffic improvements)
Brookline	traffic-signal reconstruction on Route 9
Burlington	widening or other improvements to Middlesex Turnpike
Canton	traffic-signal reconstruction
Canton	traffic signals on Washington Street at Pleasant and Dedham streets
Hingham[2]	twelve (12) locations: intersection improvements
Holbrook	five (5) locations
Lexington	redesign intersection and signals at two (2) locations

[1]The first two projects on the list (in Revere and Sudbury) are programmed to receive Consolidated Primary funds. All other projects are candidates for Urban Systems funding.
[2]Expected advertising date: June 1983.

TABLE 3-2(b)

Municipality	Project
Medford	signal updating at Mystic Valley Parkway and Winthrop Street.
Milton	thirteen (13) locations
Newton	traffic-engineering improvements and pedestrian bridge
Newton	Washington Street at Adams Street/Jackson Road/Lewis Terrace intersection (channelization and signals)
Randolph	circulation system
Randolph	three (3) locations on Route 28
Reading	traffic control signal at Route 28 and South Street
Revere	reconstruction of Broadway from Revere Beach Parkway to Revere Street
Revere[1]	reconstruction of Revere and Malden streets, sections of Broadway
Revere[2]	traffic signal reconstruction at three (3) locations
Somerville	Phase II Urban Systems
Sharon	four (4) locations, intersection improvements
Stoneham[1]	Main Street resurfacing, widening, signals, off-street parking, reconstruction
Sudbury	four (4) locations, channelization
Walpole	four (4) locations, intersection improvements
Weston	five (5) locations, intersection improvements

[1]Annual Element

[2]Expected advertising date: June 1983

The impacts of these projects on fuel consumption are apt to be quite variable, as is illustrated by the results of two 1981 CTPS studies of potential traffic-flow improvements in the towns of Wellesley and Waltham. The Wellesley study examined the re-timing of eight interconnected signals on Washington and Central streets. Improvements studied in Waltham consisted of the optimization of signal timing at five intersections dispersed throughout the periphery of the CBD. The estimated impacts of these projects included a reduction in fuel consumption per peak hour of 80 gallons for progressive signal timing in Wellesley and two gallons for signal upgrading in Waltham. Assuming four peak hours per work day and 250 days per year, this results in annual peak hour savings of 80,000 gallons in Wellesley and 2,000 gallons in Waltham, which are vastly disparate results. The difference in estimated impacts for these two projects is indicative of the range likely to be produced by most projects in the TIP, although the Waltham case may be more representative than that of Wellesley.

However, the estimated impacts reported in both the Wellesley and Waltham studies are optimistic, in that they do not account for the VMT increases which would be induced as a result of improved levels of service. To adjust for this effect, which would tend to increase fuel consumption, estimated short-term fuel-consumption savings should be lowered by 50-70 percent. Estimates of long-term savings should be reduced further; as noted earlier, improvements in highway service quality may actually result in a small net <u>increase</u> in long-term fuel consumption.

3.2 Southeast Expressway Ramp Metering

One additional set of traffic-flow improvements, not included in the TIP, which merits consideration is ramp metering on the Southeast Expressway. The 1980 CTPS <u>Southeast Expressway Lane Allocation Study</u>, referenced earlier, analyzed the effects of metering at the Neponset and Columbia on-ramps. These ramps were found to be the only locations where metering appeared to be warranted on the basis of traffic volumes. It was also judged that metering at these locations would be beneficial only from 7:00 to 8:00 AM, in the expressway's northbound direction.

The study did not include an analysis of energy impacts, but did forecast reductions in travel times related to ramp metering, which were estimated to be between 93,000 and 143,000 person-hours annually for the expressway itself. These figures do not reflect the increases in travel time which would be experienced by vehicles diverted away from the expressway to alternate routes. It is estimated in the study that these diverted vehicles would incur travel-time increases of approximately 27,000 person-hours per year, which lowers the net travel-time savings associated with the project to 66,000-116,000 annual person-hours. This may be presumed to translate into a substantial energy savings.

However, these estimates do not account for the net increases in VMT-related fuel consumption which would accompany travel-time improvements on the expressway. This effect is likely to cause a major reduction in potential energy savings. However, if metering at the Neponset ramp were accompanied by a preferential lane for high occupancy vehicles, as discussed in section 2.2, fuel-conservation impacts would be enhanced.

4.0 TRANSIT-RELATED MEASURES

INTRODUCTION

As has been shown earlier in this report, the substitution of public-transit use for auto use will, as a rule, tend to result in energy savings--not only because transit tends to be significantly more energy-efficient than automobiles, on a per-passenger-mile basis, but also because of the following factors:

- Public transportation services--and rail transit in particular--tend to promote higher-density residential and commercial development in urban areas, which in turn results in reduced rates of auto ownership, fewer vehicle trips, and shorter average trip distances; all these are factors in reducing average per person and per-household energy consumption; residential space heating also tends to be more energy-efficient in high-density, multi-unit dwellings than in single-family houses.[1]

- Electricity is used in operating rail transit; this provides the opportunity to substitute power generated from more plentiful, renewable sources for the petroleum-based fuels used to power automobiles

- Public transportation is even more energy-efficient during peak periods, when it is used to capacity; variable-work-hours programs, off-peak pricing discounts, and other measures to attract ridership in the off-peak can significantly boost the energy savings associated with public transportation systems.

Nevertheless, the value of expanding public transit services as a method of reducing transportation-related fuel consumption has been widely disputed. Not only has public transit been criticized as being too costly, but some studies suggest that many proposed transit projects could actually result in <u>increased</u> energy consumption.

This concern applies most directly to large capital projects In the past, the vast amounts of energy consumed in the process of constructing new subway facilities were frequently excluded

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[1]EOTC, "Public Transportation Services and the Conservation of Energy."

from estimates of the net energy impacts associated with these projects. Station and maintenance energy have also been omitted from studies which have focused exclusively on the propulsion energy required to operate alternative modes.

Nevertheless, even after such factors as construction and station energy requirements are taken into account, there remain numerous prospective transit projects which would be beneficial from the standpoint of energy conservation. In the case of large capital projects, a period of more than ten years may be required before cumulative energy savings resulting from reduced auto VMT offset the initial expenditure of energy for facility construction, but the potential long-term savings can be substantial. Smaller-scale projects, such as bus-routing changes or service-frequency increases, entail few indirect energy costs and may produce immediate energy savings. These issues are addressed below as they apply to conditions in the Boston metropolitan area.

There are two basic approaches which can be followed in using public-transportation improvements to conserve energy:

- increase the fuel efficiency of transit operations
- increase ridership through the diversion of former auto users to transit

While there are several transit-fuel-economy measures which may be detrimental to the goal of increasing ridership, these two conservation approaches can be compatible. Increasing ridership through expanding or upgrading services has received more attention than fuel-efficiency measures, and tends also to be more controversial. Since the basic nature of the types of measures comprised by both approaches is widely understood, the generic types are not inventoried here.

POTENTIAL APPLICATIONS IN THE BOSTON AREA

Measures to increase the fuel efficiency of transit operations are addressed in the first of the following sections. The remaining sections examine measures aimed at conserving energy by diverting former auto users to transit.

4.1 Fuel-Economy Measures

Measures included in this section are designed to reduce the quantity of energy consumed by transit operations. Many of these measures have been proposed in previous studies as contingency strategies to be implemented during an emergency energy shortage. A broad range of contingency measures can reduce fuel consumption without adversely affecting service quality, and are suitable for long-term, non-emergency applications.

Table 4-1 identifies the categories of measures which may be appropriate for implementation on transit systems under current and expected future conditions, rather than during a possible crisis period only. These measures do not entail reductions in the frequency, spatial coverage, or convenience of transit service, as do some contingency measures. Reducing the frequency of transit-vehicle stops is an example of a possible contingency measure which might lessen the convenience of transit service and thereby cause a loss of ridership under normal circumstances. This and other similar actions are not recommended as routine energy-conservation measures.

Fuel economy has been an active concern of the MBTA for a number of years. Between 1973 and 1983, annual gross energy consumption (excluding that for commuter rail) declined from 5,844,570 to 4,215,776 million BTUs. During this same period, gross energy consumption per vehicle-mile of travel declined from 132,800 to 100,500 BTUs.[1] Most of this improvement in energy efficiency can be attributed to modernization of the obsolete electric-power system. The decline in net energy output to the system has been substantially less over this time period, however.

Table 4-2 identifies MBTA energy-conservation programs which have been completed in recent years. Additional programs are underway or have been proposed. Table 4-3 lists programs which were planned for introduction in 1983, as well as proposed programs which have been deferred or cancelled. The table also lists potential dollar savings for the projects, as estimated by the MBTA Energy Conservation Office, and estimates of corresponding levels of energy savings, in gallons-of-gasoline equivalents, calculated as part of the present study.

Total potential energy savings, for the 1983 programs and those which have been deferred, are estimated to be 1.5 million gallons. This is a relatively large benefit compared to those that can be attained with most other categories of energy-conservation measures. It probably is also true that the estimated level of benefits approaches the maximum which can be achieved with this particular set of projects, and that a strong commitment will be needed to produce energy savings of this magnitude. However, there remain additional potential measures which may improve system energy efficiency; these include actions identified in Table 4-1, as well as further improvements in power transmission and distribution. Overall, it appears that the public transportation system can be made substantially more energy-efficient, and that energy savings achieved through MBTA conservation programs can have a relatively large impact on regionwide consumption levels.

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[1]"Gross energy" is considered the total fossil energy required at the source to produce electric energy.

TABLE 4-1

Transit Fuel-Economy Measures

Reduce Vehicle Idling and Delay

- new procedures for bus drivers, and supervisory personnel
- improved driver and supervisor training

Transit Vehicle-Maintenance Measures

- increased engine maintenance
- tire-pressure check and adjustment
- air filter and intake maintenance

Vehicle-Capacity and Equipment Modification

- rearrangement of seats to increase capacity
- use of radial tires
- installation of automatic photo-cell door openers, infrared/rating heating systems, improved door installation and/or air curtains in door openings

Operating-Facility Measures

- modifications of heating, ventilating, and air conditioning
- wall, window, and door insulation
- changes in the number and type of light fixtures
- employee awareness programs
- modification of space-heating and hot-water systems

Sources: Frederick Salvucci, Charles Carlson, Brian Day, David Gletner, Transportation Energy Contingency Strategies, Volume II, prepared for Federal Highway Administration and Urban Mass Transportation Administration, March 1980.

Municipality of Metropolitan Seattle, Transportation Energy Management: Current Transit Operator Activities, September, 1982.

TABLE 4-2

MBTA: Completed Energy-Conservation Programs

- Tunnel lighting de-lamping
- Elimination of radiant heaters systemwide
- De-rating new Orange and Blue Line cars
- HVAC control modifications for LRVs (dead-band temperature control)
- Automatic lighting controls, Green Line
- Evaluation of diesel-fuel additive
- Phasing out of obsolete Charlestown heating plant (No. 6 oil)
- Steam power generating plant shutdown
- Insulation of hot water supply tanks (200) and piping
- Reduction of temperatures of hot water tanks (200)
- Installation of solar hot-water systems at Charlestown and Everett
- Elimination of use of portable space heaters
- Installation of air-start engines on buses to facilitate reduced idling
- Reduced lighting loads at Park Street Station
- Reduced lighting loads at 500 Arborway
- Installation of outside temperature monitor to automatically control boiler pressures

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Source: MBTA Energy Conservation Office.

TABLE 4-3

MBTA: Energy Programs

1983 Programs	Potential Annual $ Savings	Potential Annual Energy Savings (in gallons of gasoline equivalents)
1. LRV Regeneration - 4-car Demonstration	1,000,000	300,000
2. Station De-lamping (20 stations)	200,000	60,000
3. Shared Savings Demonstration with Energy Service Company	500,000	150,000
4. Reduced Bus-Engine Idling	150,000	125,000
5. Use Blended Fuel in Buses	50,000-350,000	40,000-290,000
6. Reduced Escalator Operation	77,000	23,000
7. Lights-Off Program in Stations	200,000	60,000
8. Fuel-Management System (Pilot)	Unknown	-
9. Reduced Operation of Rail Car Auxiliary Systems	870,000	260,000
10. Disconnect Third-Rail and Track-Switch Heaters	Unknown	-
11. Discontinue Express Track Platform Operation, Orange Line	55,000	15,000
12. Phase Out Everett Heating Plant	200,000	-
13. Replace Defective Steam Traps Systemwide	Unknown	-
14. Convert Everett Boilers to Use No.4 Oil	Unknown	-
15. Boiler Fuel Preheater Demonstration	Unknown	-
16. Test and Evaluate Sylvania Energy-Efficient Lamps	Unknown	-
17. Study Fuel Recovery BET	Unknown	-
Delayed/Deferred (D) or Cancelled (C) Projects		
1. Rail Car Coasting Program (C)		
2. Reduced Train Size In Off-peak (10 Am - 2 PM) (C)	740,000	-
3. Use of Diesel-Fuel Additive (C)	None	-
4. Shut Down SBPS Combustion Turbine Generator (C)	450,000	-
5. Convert Escalators From 120 fpm to 90 fpm (C)	155,000	-
6. Install Dead-band Temperature Controls on Orange and Blue Line Cars (D)	270,000	80,000
7. Install Automatic Lighting Controls for Subway-Tunnel Lighting (D)	800,000	230,000
8. Construct New Heating Plant for Cabot Complex (D)	200,000	-
9. Install Automatic Lighting Controls Systemwide (D)	Unknown	-
10. Install Demand-Actuated Controls on Escalators (C)	500,000	-
11. Install Vandal-Resistant, Fixed-Point Thermostats Systemwide (D)	Unknown	-
12. Install Automatic Valve Controls on Radiators (D)	Unknown	-
13. Install Automatic Pressure-Control Valves on Steam Lines at Cabot (D)	Unknown	-
14. Install Automatic Layover Controls on Rail Cars (D)	Unknown	-
15. Modernize D.C. Lighting System (Part of Station Modernization) (D)	Unknown	-

Source: Program listing and annual dollar savings are from MBTA Energy Conservation Office; dollar savings have

4.2 Major Capital Projects

4.2.1 Reduction in VMT-related Energy Consumption

This report focuses primarily on the potential of small-scale projects, requiring relatively little capital investment, to reduce transportation-energy requirements in the region. Rail-line extensions and other capital projects are clearly much greater in scale than most of the projects or strategies considered in this report. However, a number of capital-intensive projects are included in this section, for the following reasons:

- These are all projects which have been included in the Transportation Improvement Program for the region, and are therefore prospective candidates for federal funding.

- The magnitude of these projects suggests a potential for large-scale energy impacts--either positive or negative.

- Estimates of the level of impacts associated with these projects serve as a useful frame of reference for evaluating the relative benefits of other measures requiring lower levels of capital investment.

Table 4-4 presents estimates of the direct changes in automobile fuel consumption associated with major new transit projects that have been proposed for the Boston metropolitan area. There are also likely to be indirect reductions in energy use which have not been estimated as part of this study. All of these projects are included in the TIP and the most recent version of the area's Program for Mass Transportation (1978). Several additional transit projects listed in the TIP are not shown in the table: (1) Green Line Extension to Brighton; (2) Bowdoin-Charles Connector; (3) Brookline Village Connector; (4) North Station-South Station Connector; and (5) Circumferential Transit. The data needed to estimate the energy impacts of these projects are not currently available. In the case of the first three, the energy savings resulting from reduced auto VMT is likely to be fairly small; i.e., under 100,000 gallons per year. The fourth project listed above, the North Station-South Station Connector, has been eliminated from current plans for the depression of the Central Artery. The prospects for implementing Circumferential Transit proposals, first formulated more than a decade ago, currently appear remote. Table 4-4 therefore includes all the major projects which both are potentially viable in the foreseeable future and may result in substantial energy impacts.

The impacts associated with extension of the Red and Orange lines to Route 128 and the Blue Line to Lynn each includes a reduction in highway VMT exceeding 1,000,000 gallons per year. However, these projects are not currently under serious consideration, in part because new rail extensions are ineligible

TABLE 4-4(a)

Major Capital Projects: Reduction in VMT-Related Energy Consumption

Project	Number of Former Auto Trips Diverted to Transit (Daily)	Annual Reduction in Auto VMT[1]	Annual Reduction in Fuel Consumption Related to Change in Auto VMT[1] (Gallons)
Red Line Northwest Extension to Alewife			
• To Arlington Heights	2,460	8.9 million	660,000[2]
• To Route 128	3,900	17.8 million	1,320,000[2]
Roxbury-South End Replacement Project	-	6.0 million-9.0 million	290,000-440,000
Forest Hills to to Needham Service (Commuter Rail)	Negligible	-	-
North Shore Transit Improvements			
• Blue Line Extension to Lynn[3]	10,000	31.0 million	1,660,200
• Commuter Rail Upgrade	2,900	16.2 million[4]	937,000
• Wonderland Station Upgrade	900	3.7 million	196,200

TABLE 4-4(b)

Major Capital Projects: Reduction in VMT-Related Energy Consumption

Project	Number of Former Auto Trips Diverted to Transit (Daily)	Annual Reduction in Auto VMT[1]	Annual Reduction in Fuel Consumption Related to Change in Auto VMT[1] (Gallons)
Orange Line Extension Oak Grove North to Route 128	10,000	21.0 million	1,025,000
Green Line Extension to Tufts	2,000	3.0 million	146,000
Rail Service to Brockton	800[5]	2.4 million	117,000

[1]Based on 300 days per year, as in Red Line Extension EIS.
[2]Red Line EIS estimated auto fuel consumption rate of 13.5 mpg is assumed.
[3]The FY 1984 TIP does not include earlier plans for a Blue Line rapid rail extension, in keeping with current federal policy.
[4]North Shore commuter rail alternative estimate based on 250 days of operations per year.
[5]Half of estimated ridership.

Sources:

- Final Environmental Impact Statement, Red Line Extension Harvard Square to Arlington Heights, August 1977.
- CTPS Technical Report Number 40, Replacement/Transit Improvement Study: Phase II Transit Patronage Estimation, July 1983.
- CTPS Technical Memorandum, "Alternative Analysis for Forest Hills-Needham Transportation Improvement Study," December 1982.
- North Shore Transit Improvements Project.
- CTPS Technical Report Number 30, Ridership Estimates, Green Line Extension, December 1981.
- Program for Mass Transportation, November 1978.

for federal funding at the present time, except for those, like the Red Line extension to Alewife, which are already under construction.

The Roxbury-South End Replacement Project is estimated to reduce automobile fuel consumption by roughly 300,000 to 440,000 gallons per year, depending upon which of a number of possible alternative bus and light-rail services under study is chosen to replace the former Orange Line rapid-transit service on Washington Street, which is being relocated along a new alignment. Unlike the rapid-rail extensions identified above, the prospects for implementation of some replacement service in the Roxbury-South End area are good.

Two other projects included in Table 4-4--the Green Line Extension to Tufts and Rail Service to Brockton--are estimated to have impacts which are smaller in magnitude than either the rapid rail extensions or the replacement service. The change in automobile fuel consumption which may be expected to result from these projects is less than half that associated with the Roxbury-South End Replacement Project, for example. The proposed Green Line project would divert relatively few current auto users to transit, since ridership would be drawn primarily from current bus riders. It has been estimated as part of an analysis currently being conducted at CTPS that commuter rail service to Brockton would attract 850 round-trip passengers per day, a substantial percentage of which are current bus riders. Both of these projects can be expected to have more modest effects on automotive fuel consumption than projects which would produce greater reductions in VMT.

Finally, the results of a recent CTPS analysis show that reinstatement of commuter rail service between Forest Hills and Needham would have minimal impact on transit ridership in the area, which is currently served by express bus. Consequently, any VMT change would also be negligible; there could, in fact, be a slight increase in auto travel.

4.2.2 Net Energy Impacts

Changes in highway fuel consumption represent only one aspect of the total energy impact associated with transit projects. To determine the net impact of the projects listed in Table 4-4, the reductions in fuel consumption noted in the table must be weighed against the energy used to construct and operate the transit projects. This includes several categories of energy consumption:

- propulsion energy for transit vehicles
- station and maintenance energy
- facility-construction energy
- vehicle-manufacturing energy

It should be noted that each of the above categories of energy consumption applies to automobiles, as well as transit. The estimates of VMT-related fuel reductions in Table 4-4 reflect changes in automobile-propulsion requirements alone, although vehicle manufacturing and maintenance energy will account for nearly half the total energy consumed in connection with automobile travel in 1985. These components of total energy consumption are ignored more frequently in the case of automobiles than transit. Estimates of net changes in energy consumption should also reflect any reduction in bus VMT which results from the introduction of new rail services.

It is not possible to generate detailed estimates of the construction- and operating-energy requirements associated with most of the projects included in Table 4-4, using available data. However, estimates of this type can be obtained or derived from the environmental impact statements for the Blue and Red Line extensions. The estimates for these projects (Table 4-5) serve to illustrate the magnitude of energy consumed for transit operations and construction, relative to the energy savings achieved through reductions in automotive VMT.

The information on operating and construction energy for the Red Line Northwest Extension applies to the route segment from Harvard Station to Arlington Heights, rather than the sections from Alewife to Arlington Heights and Alewife to Route 128, which were included in Table 4-4. The section from Harvard to Alewife was not included in the table because it is already under construction and, therefore, does not qualify as a new project. The sections of the extension closer to the core (i.e., Harvard to Alewife) are likely to have somewhat more favorable net energy impacts than those further out (i.e., Alewife to Route 128), where trip densities are lower and distances between stations are greater. Nevertheless, the figures in Table 4-4 provide a reasonably good indication of the relative magnitude of impacts which could be expected for the proposed extension between Alewife and Arlington Heights, at least.

Table 4-5 shows substantial savings in operating energy resulting from the Red Line extension and each of the North Shore transit improvements. These figures (column 3), which range from 820,000 gallons per year for the Red Line extension to 196,000 gallons per year for the Wonderland Station upgrade, represent the net decline in energy consumption resulting from reduced auto VMT, after accounting for operating energy consumed by expanded transit services. The energy required to construct each of the prospective projects is shown in column 4. Construction of the Red and Blue line extensions would require the equivalent of 13 million and 14.7 million gallons of gasoline, respectively. The construction requirements for the commuter rail improvements on the North Shore and the Wonderland Station upgrade, at 8.9 million gallons and 6 million gallons, are substantially less.

TABLE 4-5

Rail Transit Extensions: Net Energy Impacts

Project	Annual Transit Operating Energy (Gallons of Gasoline)	Net Change in Annual Operating Energy[1] (Gallons of Gasoline)	Construction Energy[2] (Gallons of Gasoline)	Years Needed to Recover Construction Energy	Annualized Construction Energy (Over 35-Year Period)	Change in Net Annual Energy Consumption (Gallons of Gasoline)
Red Line Northwest Extension-Harvard to Arlington Heights	1,625,000	-820,000	13.0 million	16	371,400	-449,000
North Shore Transit Improvements						
• Blue Line Extension to Lynn	1,264,200	-396,000	14.7 million	37	420,322	+ 24,322
• Commuter Rail Upgrade	244,250	-653,583	8.9 million	14	253,483	-400,100
• Wonderland Station Upgrade	-	-196,200	6.0 million	30	171,638	- 25,562

[1]Includes energy consumption by automobiles and Red Line/Blue Line or commuter rail

[2]For transit and commuter rail only

Column 5 shows the number of years which would be required for cumulative annual operating-energy savings (column 2) to offset the initial expenditure of construction energy. The estimated construction-energy-recovery period shown for the Blue Line extension to Lynn is over twice that shown for the Red Line extension to Arlington Heights, despite the fact that construction-energy requirements are similar in magnitude for both projects, as are estimated auto VMT savings.[1] The disparity results largely from the difference in auto fuel-consumption rates assumed in the two environmental impact statements which served as the source of the figures in Table 4-5. VMT-related energy savings were estimated using auto fuel-consumption rates of 13.5 mpg in the Red Line study and 17-19 mpg in the Blue Line study. The less efficient rate used in the Red Line study results in higher estimates of fuel-consumption savings per mile of auto travel eliminated. While the fuel-consumption rate applied in the Blue Line study is closer to that used elsewhere in this report, there is some justification for using a higher; i.e., less efficient, rate in this context. Since energy savings related to reduced auto VMT are being compared to the total energy needed to operate and construct new transit projects, it is appropriate to account for all components of auto energy consumption in the fuel-consumption rate, including operation, maintenance and vehicle manufacturing. A rate of 17-19 mpg clearly accounts for auto propulsion energy only.

Thus, data from the Red and Blue line studies present somewhat contradictory evidence regarding the long-term energy impacts of rapid transit extensions, although the apparent disparity results entirely from the difference in fuel-consumption rates used in the two studies. Over a thirty-five-year period of operation, the Red Line extension is estimated to result in a savings of approximately 450,000 gallons per year, and a Blue Line extension to produce an increase in energy consumption of 24,000 gallons per year. The North Shore commuter-rail-upgrade option, which was analyzed using the same auto fuel-consumption rate applied in the Blue Line study, is estimated to produce a net savings of 400,000 gallons per year.

Overall, it appears that transit projects which require substantial capital investment may result in significant energy savings over their operating lifetimes, if these projects result in the diversion of large numbers of auto users to transit. For prospective rapid-rail extensions in the Boston area, the period required to recover the initial investment of construction energy

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[1] Extension of the Red Line from Harvard Station to Arlington Heights is estimated in the EIS to result in a reduction of 110,000 VMT per day, which is equivalent to 35 million VMT annually.

is likely to exceed 15 years. Conditions affecting energy consumption, such as the state of auto- and transit-vehicle technology, may change over this time period in ways which are presently difficult to predict. From the perspective of current trends, however, it is reasonable to conclude that rail extensions and other new transit services will result in substantial long-term energy savings. Commuter-rail improvements and bus projects will yield net energy savings sooner than more capital-intensive rapid-rail extensions.

4.3 Expansion of Bus Routes

Bus transportation can be a highly energy-efficient mode. Unlike rail systems, buses generally require only modest investments in construction of fixed facilities. Taking into account the total amount of energy required by bus and automobile transportation (for vehicle manufacturing and maintenance, etc., as well as for propulsion), buses can carry on average less than six passengers per vehicle-mile and still match the 1985 energy efficiency of automobiles carrying an average of 1.4 passengers per vehicle-mile. Another way to view this relationship is to compare fuel-consumption rates for the 1985 vehicle fleet: 20.5 mpg for automobiles and 3.6 mpg for MBTA buses.

When bus routes are significantly more circuitous than the auto trips they replace or a significant amount of energy is consumed in accessing bus routes by auto, the relative fuel efficiency of buses declines. Nevertheless, it is clear that bus operations can produce energy savings even if average load factors are low. From the standpoint of energy conservation, buses can be used efficiently in a wide variety of situations to reduce auto travel. It is important, of course, that bus operations also meet a reasonable standard of cost-effectiveness.

The MBTA currently operates more than 150 bus routes, each of which is designed to serve one or more of the following functions:[1]

- linehaul
- feeder/distributor
- crosstown
- inter-community
- intra-community

These routes, combined with the rail and trolley transit lines, provide a high level of service to the Boston metropolitan area, in terms of spatial coverage.

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[1] CTPS, Prototype Bus Service Evaluation Study: SENTRY - A Transportation Reporting System, Draft Report.

The potential for expanding the existing bus route system is constrained by several factors. The rapid and light rail lines, rather than buses, form the core of the transit network; the rail system, obviously, is spatially fixed. Thus, the configuration of the rail transit system limits potential bus-service options. The MBTA must also be concerned about the effect of new routes on private bus lines.

There are, however, several potential opportunities for expanding MBTA bus service which may be viable not only in terms of energy conservation, but also in terms of cost-effectiveness. Perhaps the most extensive of these would be service to a number of the concentrated pockets of development along Route 128.[1] This would be most likely to include office parks in Beverly, Peabody, and Danvers on the North Shore, and Norwood in the southwest corridor. These new services can be viewed as serving some of the functions that a circumferential transit system would be designed to perform.

Additional data would be needed to produce detailed estimates of the energy impacts associated with these services. However, the analysis below provides an indication of the general magnitude of potential impacts. The following characteristics are assumed for a new service connecting downtown Boston with the Beverly-Danvers-Peabody area:

Round-trip distance: 35 miles
Number of bus round-trips per day: 10
Average ridership per trip (one-way): 20
Average round-trip distance for auto trips diverted to bus: 14 miles
Average occupancy for diverted auto trips: 1.4 passengers

The estimated energy savings for the service, given these assumptions, are modest: approximately 40 gallons per day (10,000 gallons per year), considering propulsion energy alone, and approximately 80 gallons per day (20,000 gallons per year), taking into account total modal energy consumption. Bus service to Norwood office parks would be likely to result in impacts of similar magnitude.

Two factors are responsible for the low impact levels estimated above: relatively low levels of service and a high degree of bus-route circuity. Both of these conditions are characteristic of most new bus services that could be added to the existing system, which is already quite comprehensive.

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[1]Bus alternatives considered as Orange Line alternatives in the Roxbury-South End area are included in the previous section of this report.

However, another possible option which would have greater energy-conservation potential, and which is likely to be more cost-effective, would be to extend existing routes (e.g., Routes 400 and 450 on the North Shore; Route 34E to the south of Boston) to serve the Beverly-Danvers-Peabody and Norwood office parks. This is feasible only if the schedules of existing routes can accommodate the route extensions without substantially increasing headways or adding more than a few buses.[1] Assuming that the extensions would add 15 miles to current round-trip bus routes, and that ridership and other characteristics remain the same as in the previous analysis, the estimated maximum savings is 75 gallons per day (18,750 gallons per year) in terms of propulsion energy alone, and 120 gallons per day (30,000 gallons per year) taking into account total modal energy consumption.

A route extension of the type described above has already been done in the case of Route 350, between Boston and Burlington. The route has been extended along an approximately three-mile loop to serve the Burlington Mall and adjacent development. Data for the off-peak period between 10:00 AM and 1:30 PM show that trips to and from the mall area account for 16-60 percent of the route's ridership. It is likely that this route extension has resulted in reduced energy consumption.

Another potential new bus service might be a crosstown route designed to serve the Kendall Square area in Cambridge, which is currently undergoing intensive development. The magnitude of energy impacts associated with a service of this type would depend on such factors as route configuration, ridership, and users' former modes; determination or estimation of such factors is beyond the scope of this report. The range of impact for a service of this type is likely to be between zero and 100 gallons saved per day, or no more than 25,000 gallons per year. Impacts are estimated to be relatively small in magnitude because the area is already served by the Red Line and is within reasonable walking distance of Lechmere Station.

The services analyzed above are not intended to represent an exhaustive inventory of potential bus-routing changes. They do, however, illustrate the types of expanded services which could be provided, and the probable range of their energy impacts. It appears that these new or extended services would produce energy savings which, on an individual-route basis, are small in magnitude. However, the cumulative savings resulting from multiple route extensions or new routes could be substantial.

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[1]While it is possible to add more than a few buses to the route, the resulting increase in operating costs and energy consumption would be much the same as that for creating an entirely new route between Boston and North Shore office parks.

4.4 Increases in Service Frequency

Another possible option for attracting auto trips to the transit system is to increase the frequency of service on existing routes, rather than expand the system's spatial coverage. The MBTA system as a whole operates at reasonably high rates of frequency which are generally consistent with the demand for individual services.

Scheduled headways are shortest on the rapid and light-rail transit lines, ranging from four to six minutes during peak periods and eight to ten minutes during daytime off-peak hours on the Red, Orange, and Blue lines, and six to eight minutes during peak periods and seven to ten minutes during daytime off-peak hours on the Green Line. Night and weekend headways are generally in a range similar to that for off-peak daytime hours, although there are periods of nighttime and Sunday operations when some scheduled rapid-transit headways are as long as 15 or 16 minutes.

Service is typically more frequent on the rapid transit lines than bus routes, which is not surprising since the highest trip densities usually occur in areas served by rapid transit. The MBTA operates more than 150 bus routes, 40 percent of which have peak-period headways of 15 minutes or less, and 20 percent of which have headways of 10 minutes or less during peak hours. During daytime off-peak periods, headways are 15 minutes or less on 10 percent of the routes and 12 minutes or less on 5 percent of the routes.

Headways are longer on the commuter rail system than the bus routes. Peak-period headways range from 20 to 40 minutes on MBTA commuter rail. Daytime off-peak headways are generally one hour or longer, while night and weekend headways often exceed one hour. There is no service on some of these routes during night and weekend periods, although most bus and rapid transit lines do operate at these times.

While the frequency of public transportation service in the region may be considered adequate, there is no doubt that headways could be shortened on the bus and commuter rail routes, and that this would result in increased ridership. The following analysis serves to illustrate the potential impact of widespread reductions in service headways.

The effects on transit ridership of changes in fares or in levels of service is frequently expressed in terms of demand elasticities. Transit-demand elasticity is a measure of the change in ridership which occurs in response to a change in fare or service levels. Elasticity values have been calculated and analyzed over the years for numerous fare and service changes which have been implemented for virtually every type of transit service. This vast experience has revealed a fair degree of regularity in the values of service and fare elasticities.

A comprehensive review of historical elasticity data is presented in a 1980 report prepared for the Urban Mass Transportation Administration.[1] This report corroborates earlier perceptions that the ridership response to changes in service headways is greater than that associated with fare changes, although demand is usually inelastic with respect to both headway and fare changes (i.e., the impact on ridership is less than proportional to the change in headway or fare). The mean value for both bus- and commuter rail-headway elasticities reported in this study is -.47.[2]

This elasticity can be applied to generate a rough estimate of the effects of headway changes on bus ridership and, indirectly, energy consumption. A count taken in November 1981 shows the number of weekday bus trips to be 178,885 and the number of combined bus and rapid transit trips to be 194,218. If all bus headways in the system were reduced by one-half, the predicted impact based on a -.47 elasticity value would be an increase of 67,000 bus-only trips and 29,000 combined bus and rapid transit trips. Assuming that one half of these trips represent diversions from automobiles, that average auto occupancy is 1.4 persons, and that the average distance of these trips is 12.5 miles, the estimated impact is a decline of approximately 430,500 VMT per day. This yields a savings of 21,000 gallons per day in automotive fuel consumption, assuming a fuel consumption rate of 20.5 miles per gallon[3], or 6.3 million gallons per year.[4] However, when the additional fuel consumption associated with expanded bus operations is taken into account, a large share of this apparent savings is eliminated. MBTA bus operations generate approximately 23 million VMT per year, resulting in energy consumption of approximately 6.8 million gallons of diesel fuel at expected 1985 fuel-consumption rates.[5] If service frequencies and VMT were doubled, this would result in an increase in energy consumption of approximately 6.8 million gallons. The net impact of the service change would therefore be negligible savings or possibly an increase in energy consumption.

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[1] Patrick Mayworm, Armando M. Lago, J. Matthew McEnroe, Patronage Impacts of Changes in Transit Fares and Services, prepared for Urban Mass Transportation Administration, September 1980.

[2] This is an arc elasticity defined as follows:

$$Earc = \frac{\log Q2 - \log Q1}{\log F2 - \log F1}$$

where Earc is the arc elasticity calculated for the change in ridership and fare (or service) levels from (Q1, F1) to (Q2, F2)

[3] Propulsion energy only.

[4] Assuming 300 operating days per year.

[5] In terms of Btu values, one gallon of diesel fuel is equivalent to approximately 1.1 gallons of automotive gasoline.

The above analysis is simplistic, in that the elasticity value used may not accurately reflect demand response in a system with a high level of service. However, it is likely that the actual response would differ by no more than 20 percent of the value estimated. In any event, widespread reductions in bus-service headways are unlikely to occur in the foreseeable future. Federal subsidies for transit operations are expected to be reduced in the next few years, and financial assistance from the state and municipal governments in Massachusetts is constrained as a result of Proposition 2½. Reliance on fare revenue to cover operating costs is therefore apt to increase in the future, and any major service changes of necessity will be required to meet a high standard of cost-effectiveness. While energy prices remain stable, there will not be sufficient additional ridership to meet the costs of widespread reductions in bus-service headways. This situation may change dramatically, however, if energy prices increase.

4.5 Fare Reductions

As noted in Section 4.3, the effect of fare changes on transit ridership has been studied extensively. Fare elasticities have been found to vary widely, depending on such factors as city size, trip distances, time of day (i.e., peak vs. non-peak), and income and age of riders. A recent analysis of 67 transit-fare changes yielded an estimated elasticity mean and standard deviation of -0.28 ± 0.16.[1] This value does not differ significantly from the long-standing Simpson and Curtin rule of thumb that transit ridership will change 0.3 percent for every one-percent change in fare.

Recent data on fare elasticities in the Boston area are available from a CTPS analysis of the impacts associated with the 1981 MBTA fare increase. This study reports the elasticity for total unlinked trips[2] to be -0.27, based on an increase in regular adult fares from 50 to 75 cents for rapid transit and 25 to 50 cents for buses. In terms of ridership counts, this reflects a loss of 56,700 trips (9.4 percent) from a base total of approximately 600,000 trips. The ridership loss is estimated in this study to yield an increase of 70.6 million VMT annually, which is translated into a predicted increase in energy consumption of 5.4 million gallons per year.[3]

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[1]Mayworm et al., Patronage Impacts, p. 19.

[2]Data on unlinked trips are not adjusted for transfers or "links" between transit vehicles, but count each link as a separate trip.

[3]In response to ridership losses resulting from the fare increase, the rapid transit fare was reduced to 60 cents in May 1982.

The results of this study show that the ridership response to transit-fare changes may be inelastic and at the same time produce major energy-consumption impacts. This would appear to suggest that fare reductions could be an effective means of saving energy. In fact, there have been a number of reduced-fare and free-fare experiments over the past decade throughout the U. S., the purpose of which has been to induce increased ridership. However, the near-term prospects for fare reductions on the MBTA system are remote. The MBTA faces a pressing need to increase or, at a minimum, maintain farebox revenues, as a result of declining public financial assistance. The relevant issue, from the standpoint of energy conservation, is more likely to be the consequences of a fare increase, rather than the potential benefits of a fare reduction. On the basis of the results of the 1981 fare increase, it can be anticipated that any future system-wide fare increases would produce substantial adverse energy impacts.

Employer-subsidized transit-pass programs are an alternative to system-wide fare reductions which may effectively lower costs for some users. Obviously, the ridership impacts of such programs will depend on the willingness and ability of area employers to participate. The primary role of the MBTA and state-level public agencies would be to market and promote this type of action among area employers. These agencies can thus affect but not control the scale of pass-subsidy programs.

While it is unlikely that the MBTA will lower base transit fares, there is a better chance that selective pricing changes may be implemented. Specifically, it may be feasible to reduce or eliminate fees at some of the MBTA's commuter-parking facilities. The MBTA currently operates nearly 100 commuter-parking facilities. Fees ranging from 25 cents to $2.00 per day are charged at over one third of these lots and garages, some of which are not fully occupied. Parking-fee reductions at these under-utilized facilities may serve to increase not only occupancy rates, but transit ridership as well.

The magnitude of any such potential ridership increases would be relatively small. Until recently, there was a total of just over 1,200 spaces in MBTA commuter lots at which fees were charged and occupancy rates were low. The Route 128 Station lot accounted for 750 of these spaces, more than half of which are presently occupied on an average weekday. In April of 1983, the $1.00 fee at the Route 128 lot was eliminated on an experimental basis. The results of this experiment were as follows:

As of July 1983, approximately 50 vehicles per day had switched from the Canton Junction Station to Route 128, while 20 vehicles had switched from Route 128 to Canton Junction. These shifts do not represent net changes in transit ridership. However, an additional 25 vehicles were counted at the Route 128 Station which had not formerly been counted at the Canton

Junction lot. This group of vehicles may include both diversions from other commuter rail stations and new transit users. At a maximum, the increase in transit ridership would not exceed 40-50 passengers.

If the results of this experiment are extrapolated to the remainder of facilities where fee reductions may be warranted, the estimated maximum increase in ridership would be under 100 passengers per day. This translates into an annual reduction in energy consumption of less than 29,000 gallons per year.

4.6 Upgrading, Maintenance, and Rehabilitation of Equipment and Facilities

This category includes improvements that can affect the reliability, comfort, or convenience of transit service, all of which can in turn influence transit-ridership levels. The majority of projects included in the Transit Element of the TIP can be considered to belong in this broad category, as would any project designed to maintain or improve service quality without actually increasing the quantity of service in terms of frequency or vehicle-miles traveled. The projects shown in Table 4-6 are those listed in the TIP which are likely to have a substantial effect on the overall performance of the transit system.

It is difficult to quantify the effects of track, vehicle, or facility conditions on transit-system performance, and also difficult to estimate the ridership impacts associated with such service attributes as reliability, comfort, and convenience. Although it may not be possible to assign numerical values to the relationships among these values, it is nevertheless clear that the condition of transit equipment and facilities will affect service characteristics, and that these will in turn have an effect on ridership levels.

Numerous attitudinal surveys attest to the importance of such characteristics as reliability, comfort, and convenience in determining travel-mode choice. Reliability, in particular, has been shown to be among the most critical of service attributes, and there is some survey evidence indicating that reliability is of greater importance to transit riders than either travel time or trip cost.[1]

The types of projects included in this category are particularly important in the Boston metropolitan area, due to the advanced age of some segments of the transit system. Maintaining and improving the reliability of the system requires investment in equipment and facilities. Such investment should thus be viewed as playing an important role in promoting transit ridership and energy conservation.

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[1]Mayworm et al., Patronage Impacts.

TABLE 4-6

Transportation Improvement Program 1984-1988:
Projects Likely to Have Ridership Impacts

- Signal Improvements/Communications
- Transit Efficiency Program
- Track Improvements
- Station Modernization
- JFK/UMASS Station
- Kendall Station
- Commuter Rail Improvement Program
- Silverbird Rebuild Program
- Reconstruction of Budd Cars
- LRV Improvements
- Arborway Garage
- Purchase of 100 Buses
- South Station Transportation Center
- Acquisition of Additional Red Line Cars

4.7 Provision of Additional Park-and-Ride Lots

There is evidence that shortages of commuter parking spaces currently constrain ridership on MBTA rapid-transit and commuter-rail lines. An inventory of transit-parking-facility capacity and usage was conducted in support of the 1981 CTPS Technical Report 28, Regional Transit Parking Demand Analysis. That study identified a number of rapid transit stations where off-street parking capacity is deficient. At these facilities, there is a spillover of more than 50 vehicles to on-street spaces in the vicinity of the transit station. A total of 1,220 such spillover vehicles was counted for the region as a whole.

This figure represents only a small share of the unsatisfied demand for transit parking spaces. In the report cited above, it was estimated that there is a potential demand for approximately 5,400 new transit parking spaces among current automobile users.[1] This potential demand for park-and-ride spaces consists of persons who would be diverted to transit use if adequate off-street parking were available. Meeting this demand would thus result in a sizable increase in transit ridership and a concomitant decline in auto VMT.

The MBTA is currently embarked on a Transit Park-Ride Improvement program which will provide 4,100 commuter parking spaces at new facilities and upgrade conditions at existing facilities to provide an additional 1,000 spaces. It is estimated in an Appendix to the 1983 TE/SIP[2] that this program will result in an annual reduction in energy consumption of 615,000 gallons, assuming an average automobile-fuel-consumption rate of 20 mpg. This figure does not reflect the energy which would be required for construction and maintenance of new or improved parking facilities; accounting for these factors would result in only a small reduction in estimated energy savings.

The MBTA program will fall short of meeting potential park and ride demand by 900 spaces. Providing these additional spaces would result in further energy savings equal to approximately 110,000 gallons per year. The total energy savings which could be achieved by providing new transit parking facilities thus exceeds 700,000 gallons per year, for the short term. In the future, potential transit-parking demand can be expected to increase, as will the magnitude of energy savings which can be attained by meeting this demand.

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[1] Vehicle-occupancy rate: 1.61.

[2] Central Transportation Planning Staff, Individual Reasonably Available Control Measure (RACM) Analysis, Appendix A of the Transportation Element of the State Implementation Plan for the Boston Region, February 1983.

5.0 INCREASED USE OF CARPOOLING AND VANPOOLING

Ridesharing in its various forms is a highly effective means of conserving energy. Vanpooling has been shown to consume less energy per passenger-mile than any other mode, and carpooling, with an average of three passengers per vehicle-mile, is comparable in terms of fuel efficiency to commuter rail and light-rail transit. Moreover, public ridesharing programs require only modest amounts of funding assistance.

Carpools consume energy at approximately the same per-vehicle-mile rate as low-occupancy automobiles, and the fuel-consumption rate for vanpools is roughly 30-percent higher than that for automobiles on a per-vehicle-mile basis. However, the higher occupancy rates of carpools and vanpools reduce the amount of energy consumed per passenger-mile to levels substantially below that of typical automobile trips. Vanpool occupancy averages nine passengers per vehicle-mile nationally. At average occupancy rates, total energy consumption per passenger-mile for automobiles[1] is twice that of carpools, and over four times that of vanpools. Unlike most public transportation services, carpools and vanpools may operate in a peak-period, peak-direction mode only, which produces consistently high line-haul load factors.

The fuel economy of carpool and vanpool trips is reduced somewhat from that suggested above by the greater circuity of these trips. It is also important to note that ridesharing is suited only to certain types of trips. This is particularly true of vanpooling, which requires that a relatively large number of trips have compatible origins and destinations, as well as time schedules. Vanpooling and carpooling most frequently serve commuter work trips. Vanpooling is a feasible option primarily in the case of trips with line-haul distances greater than fifteen miles, which eliminates a substantial share of the commuting market. Also on the negative side, there is frequently a concern that vanpooling and other ridesharing programs will divert riders away from public transportation services. Recent research indicates that the energy savings commonly ascribed to ridesharing tend to be overstated, often by as much as a factor of two. In addition to the greater degree of trip circuity associated with carpooling and vanpooling, relative to single-passenger auto trips, the following factors tend to reduce energy savings:[2]

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[1]Average occupancy rate: 1.4 passengers.

[2]George Kocur and Chris Henrickson, "A Model to Assess Cost and Fuel Savings from Ride Sharing," Transportation Research, August 1983, pp. 305-317.

- day-to-day variations in carpool participation, due to vacations, sickness, business travel
- breakup of carpools and vanpools over time, due to changes of residence and employment
- effect of intermediate stops during the commute
- former mode of participants
- added use of vehicles left at home

Data from the 1980 U. S. Census show that 19.8 percent of the nation's work force travels to work by carpool or vanpool, which represents a small increase over the 19.4 percent of commuters who used carpools or vanpools in 1975. The Census reports that in the Boston SMSA, the percentage of workers which commutes by carpool is 16 percent, which is lower than the national average, while fewer than one percent of workers travel by vanpool. It is also important to note that 72 percent of the region's carpoolers travel in two-person carpools; only four percent of all commuters in the SMSA carpool in groups of three or more persons.

Figures compiled in late 1982 by the Massachusetts Department of Environmental Quality Engineering show that among businesses in the MAPC region with more than 250 employees, 27 percent of the labor force commutes by carpool and one percent travels to work by vanpool. Since these figures are based on estimates reported by the businesses themselves, which are required to maintain ridesharing programs, some upward bias of the data is possible. It is also likely that carpool/vanpool rates are lower among smaller businesses, which are not required to maintain ridesharing programs and which have a smaller pool of candidates among which suitable carpool/vanpool matches can be formed. It should also be noted that vanpooling accounts for only a small share of total work trips, even among large businesses which report to DEQE. In fact, businesses of more than 500 employees constitute the greatest share of the vanpool market, although there are several companies in the 250-500-employee range within the region which currently have one or more vanpools in operation.

Over the past decade, numerous public ridesharing programs have been implemented throughout the U. S. These have typically incorporated one or more of the following elements:

- computerized carpool matching
- marketing and promotion
- third-party vanpool services, including acquisition and deployment of vans, provision of insurance, and administration of user charges, and passenger fares
- priority treatment measures
- provision of commuter parking facilities

The last two categories listed above are often implemented independently from other program elements by state or local highway

departments, since they need not be coordinated with other ridesharing-promotion efforts. Preferential treatment of high-occupancy vehicles is considered separately from other ridesharing measures in this report, in chapter 2.0.

Status of Ridesharing Programs in the Boston Metropolitan Area

The state initiated its Masspool ridesharing program in 1975. In 1978 the program evolved into Masspool, Inc., a private, non-profit corporation established to provide third-party vanpool brokerage services. The "Caravan" vanpool program marketed by Masspool was operating 34 vans, serving 500 people, by July 1982. The program has grown steadily and currently administers a fleet of 135 vans. The corporate name of the agency responsible for the program was changed in 1982 to Caravan for Commuters, Inc.

Although Caravan has concentrated in previous years on its vanpool program, the corporation has been funded since July 1983 to provide coordinated regional ridesharing services. Caravan's operations have thus expanded to include the following activities, in addition to vanpool brokerage:

- computerized carpool matching
- carpool marketing through employers and community groups
- coordination and dissemination of schedules and other information on regional public transportation services

There are currently 2,500 names of individuals on file in Caravan's carpool data bank.

Another important aspect of the region's ridesharing-promotion effort is the provision of fringe parking facilities for the use of carpoolers. In the absence of a common meeting location, the time required for collection of passengers may present a significant barrier to carpool formation. The Massachusetts Department of Public Works currently operates 20 fringe parking lots serving Boston area commuters; the total capacity of these facilities is approximately 3,780 spaces. In addition, the DPW has proposed the building or expansion of facilities at ten sites, which would double the existing fringe parking capacity.

There is evidence that shortages of fringe parking spaces currently act as a constraint on carpool formation in the area. The DPW has estimated that an additional 9,000 to 18,000 fringe parking spaces could be provided to serve carpools.

Energy Impacts

In Caravan's 1982 annual report, it is estimated that the operation of its fleet, which then numbered 100 vehicles, eliminated 12 million VMT and saved 576,000 gallons of gasoline for

the year. It is expected that the scale of Caravan's vanpool program will increase over the next few years, although, for reasons cited earlier, there are practical limits on the size of the potential vanpool market.

In an analysis prepared in late 1980 by a member of the EOTC staff, it was estimated that the maximum potential for vanpooling in the region would be a fleet of 500, and that the Caravan program could attain this by 1985.[1] The projected energy savings associated with the program at this level of operation were estimated to be nearly 2.5 million gallons annually. However, actual savings are apt to be substantially lower due to factors cited earlier in this section.

It is reasonable to assume that there is significant potential to increase carpool usage in the region. As noted earlier, the percentage of commuters who carpool in the region is presently lower than the national average, and occupancy rates among existing carpools is low. The region's relatively low carpool-participation rates can probably be explained, at least in part, by the high level of public transportation services available, and relatively high transit ridership levels. Nevertheless, there is undoubtedly some potential to increase carpool rates among current users of low-occupancy automobiles, by increasing the number of fringe parking spaces and expanding ridesharing-promotion efforts. The following analysis is intended to indicate the range of impacts which can reasonably be expected from this type of multifaceted approach to regional carpooling.

If all of the 2,500 individuals currently included in Caravan's carpool data bank were placed in carpools with an average occupancy rate of 2.25,[2] the resulting impact would be a decline of 29,300 VMT and savings of 1,400 gallons of gasoline per day, assuming the following trip characteristics:

- average one way travel distance: 12 miles
- increase in trip circuity associated with carpooling: 15 percent per person-trip
- former mode: single-passenger auto

Annual energy savings would equal 350,000 gallons.

A reasonable estimate of the maximum potential increase in carpooling might be one percent of the total number of commuters

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[1]Howard Morris, "Analysis of Transportation Impacts of Massachusetts' Third-Party Vanpool Program," Transportation Research Record 823, Transportation Research Board, National Academy of Sciences, 1981.

[2]Average Boston SMSA carpool occupancy rate calculated using 1980 U. S. Census data.

currently using private vehicles, or 13,000 individuals, which is equivalent to six percent of the current number of carpoolers in the region. Assuming the same travel characteristics as above, the resulting impact would be a decline of 126,000 VMT and 6,160 gallons of gasoline consumed per day. This is equivalent to an annual energy savings of 1.5 million gallons per year.

The estimated range of potential energy savings which may be achieved through a regional public ridesharing effort is thus 350,000 to 1.5 million gallons per year. This is a large savings relative to many of the other measures considered in this report. It should be emphasized, however, that attainment of energy savings approaching this magnitude would probably require both a substantial increase in the number of regional fringe parking spaces, and a comprehensive carpool marketing and matching effort. It is also important to recall that these estimates are likely to be somewhat optimistic, since such factors as daily variation in carpool participation will tend to reduce actual energy savings.

6.0 VARIABLE WORK HOURS

Transportation systems are most severely stressed during peak commuter hours. Both highways and transit services would be, under ideal circumstances, designed to accommodate peak demand volumes; ideal conditions are rarely attained, however, due to financial and physical constraints which limit expansion of capacity. Moreover, facilities designed to accommodate highly concentrated peak traffic volumes are inefficient, in that off-peak travel volumes are substantially lower than capacity.

Variable-work-hours programs are designed to reduce the concentration of peak-period travel by extending the time interval during which people commute to work. Staggered work hours and flextime are two types of variable-work-hours program. Under staggered-work-hours programs, employers designate several different shifts of employee arrival and departure times. Flextime programs vary in the limits they impose on employee arrival and departure times. Most frequently, all employees are required to be at work during a core period, usually from 9:30 or 10:00 AM to 3:00 or 3:30 PM, and to work a specified total number of hours; subject to these limits, employee arrival and departure times are a matter of personal discretion. Variants of the program allow workers more or less flexibility in choosing their times of arrival and departure.

Another work-schedule innovation that may produce transportation benefits, which need not be implemented in conjunction with staggered work hours or flextime, is the compressed or four-day work week. The compressed work week does not necessarily have the effect of extending the daily peak period, but does result in a reduction in commuter travel by eliminating two one-way work trips per week that would normally occur during peak periods.

The most obvious benefit resulting from variable work hours is reduced delays and travel times for auto commuters, who can travel during off-peak periods. The effects of both staggered work hours and flextime on ridesharing and transit use are more ambiguous. Increased variability in commuting schedules may reduce the feasibility of coordinating carpool and vanpool trips. Improved highway travel times may serve as a disincentive to the use of public transportation services. In addition, transit-service frequency is lower during off-peak periods than peak hours, which may serve to increase auto use to the detriment of transit ridership. In this regard, compressed work week programs should be distinguished from variable work hours, since the former are less likely to induce shifts from high-occupancy modes to single occupant automobiles.

However, variable-work-hours programs are not necessarily detrimental to transit ridership. In many cases, extending the peak commuting period may produce a more efficient distribution of transit demand in relation to system capacity, resulting in improved service and increased ridership. An excess of passengers during the height of the peak period can prolong station dwell times, resulting in substantially slower travel times, which in turn reduce system capacity and service frequencies. On systems like the MBTA, which experience their highest traffic volumes during periods of one hour or less, peak travel-demand periods may be extended significantly without exceeding the times when peak service frequencies are in effect. Transit service operates at peak-period frequencies for several hours during both the morning and afternoon.

In fact, a flextime experiment conducted at the U. S. Department of Transportation's Transportation Systems Center (TSC) in Cambridge provides evidence of the positive effects of variable work hours on ridesharing and transit ridership. Six hundred TSC employees who were normally required to work from 8:15 AM to 4:45 PM were allowed under the flextime experiment to arrive between 7:00 and 9:30 AM and leave at 3:30 PM or later, after completion of an eight-hour workday. It was found that, as a result of the experiment, 9 percent of those who had modified their work schedules changed their regular mode of travel to work. The number of employees traveling by carpool increased by 5.6 percent, and the number using transit increased by 4.6 percent. The number of employees driving to work alone decreased by 6.8 percent.[1] TSC estimated the overall effect of the experiment to be a six-percent decline in fuel consumption, resulting from both modal shifts and increased operating speeds for auto commuters. It should be noted, however, that the TSC results are not necessarily representative of the impacts of variable work hours in general, since most TSC employees are transportation professionals and may be transit-oriented; in addition, TSC has convenient access to Kendall Square Station on the Red Line.

The results of a survey conducted several years ago by the Commonwealth's Division of Personnel Administration (DPA) indicated that, among employees participating in variable-work-hours programs, use of public transit increased by 5.8 percent and single-occupant auto use declined by 6.4 percent.[2] These findings lend support to the results of the TSC experiment. However, any attempt to generalize the results of these studies should be approached with caution. While it appears that variable work

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[1]Patricia Monahan, CTPS Memorandum, "Energy Contingency Plan Measures, Variable Work Hours, Compressed Work Week," March 9, 1981.

[2]Association for Public Transportation, The Variable Work Hours Program, Final Report, June 1980.

hours may, under certain circumstances, increase the use of high-occupancy modes, it is difficult to forecast the extent of potential mode shifts and associated reductions in energy consumption.

Compressed work weeks are unlikely to have a significant effect on modal shares, although there would be some decrease in transit ridership resulting from reduced trip frequency; carpool and vanpool occupancy might also decline if work days are staggered. Since compressed work weeks cause an absolute reduction in the number of commuter trips, the impacts of these programs will produce larger VMT-related reductions in energy consumption than variable work hours. However, there would be some increase in non-work travel on worker's days off, which would partially offset these savings. Compressed work weeks may allow employers to close their operating facilities one day per week, which would reduce space-heating requirements.

Status of Variable-Work-Hours and Compressed-Work-Week Programs in the Boston Metropolitan Area

The MBTA has been promoting variable work hours for several years through its Marketing Program. A survey conducted as part of a 1980 MBTA-sponsored evaluation indicated that 240 transit-served work places with nearly 85,000 employees had variable-work-hours programs in effect. This represents approximately six percent of the workers in the Boston metropolitan area. While there are many organizations which cannot adapt to variable work hours, there is undoubtedly significant potential to expand the number of existing programs.

Substantially fewer employers have instituted compressed work weeks than variable work hours. Reducing the work week to four days is more frequently viewed as a short-term response to an energy emergency than as an element of a continuing conservation program. Since the implementation of four-day work weeks generally requires a more fundamental organizational change than variable work hours, it may be anticipated that adoption of the former on a continuous basis will increase at a much slower pace.

Energy Impacts

The future energy impact of variable-work-hours programs in the Boston area will depend on a variety of factors, the most critical being the number of additional employees who are affected. While the potential for more widespread application of variable work hours appears good, quantification of this potential is highly speculative.

If the proportion of Boston-area employees participating in variable work hours programs could be increased from six to ten percent, nearly 46,000 employees would be added. A five-percent increase in the number of transit users among these employees, which is consistent with the results reported by TSC and the

Commonwealth's DPA, would reduce VMT-related gasoline consumption by 3,000 gallons per day, or approximately 670,000 gallons per year. Since it is not clear that the TSC and DPA results are generally representative of the impacts of variable work hours, this figure should be regarded as an upper-bound estimate. However, this estimate accounts only for the energy savings associated with increasing the transit mode share. There would also be a reduction in energy consumption due to the shift of some auto commuters to off-peak travel, when travel speeds are higher as a result of reduced congestion.

It has been estimated that approximately 60 percent of Massachusetts employees could be switched to a four-day work week, which would result in an energy savings of approximately 941,900 gallons of fuel per week.[1] However, it is unlikely that participation rates would approach the 60-percent level even during an energy emergency. Under conditions of stable energy supplies, an ambitious target might be a one- to two-percent reduction in weekly home-based-work trips, which would produce energy savings of 9,600-19,000 gallons per week, or approximately 480,000 to 950,000 gallons per year.

These estimated savings are large compared to those associated with a number of other energy-conservation strategies. However, since variable-work-hours and compressed work week programs are employer-based, the ability of state-level public agencies to influence the adoption of these measures is limited.

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[1]Monahan, "Energy Contingency Plan Measures."

7.0 BICYCLING

The use of bicycles as a transportation mode has grown dramatically over the past decade, in percentage terms. This increase can be attributed in part to the various energy-supply shortages and the rise in gasoline prices which have occurred during this period, as well as to greater public interest in the health benefits resulting from this form of exercise. Data for the Boston area attest to the growth in popularity of bicycling during recent years. Bicycle volumes were recorded on October 9, 1975, and again exactly five years later on October 9, 1980, at 11 intersections in or near the Boston core. Another set of counts was taken on May 5, 1976, and May 13, 1981, at four intersections within this same area. The average five-year increase in bicycle volumes at these intersections was 44 percent, which is equivalent to an average 7.5-percent annual compound rate of growth.[1]

The increasing rate of bicycle use is of minor significance from the standpoint of total transportation-related energy consumption, however, since this mode still accounts for only a small share of total regional travel. According to the 1980 census, 7,857 persons in the Boston SMSA commute to work by bicycle; this is 0.6 percent of the SMSA's total workforce. However, the census figures understate average year-round bicycle use, since the data reflect late-winter/early-spring mode-choice behavior, while bicycle ridership is highest during warm weather.[2] Data from other sources suggest that the use of bicycles is 2½- to 3-times greater in the summer than during the time period represented by the census data.

It is also important to note that energy savings result from increased bicycle use only to the extent that bicycling replaces automobile travel. In fact, recent surveys conducted in Pennsylvania and Washington, D.C. show that 40 to 75 percent of bicycle trips do not represent diversions from automobiles,[3] but instead are substitutions for transit and walking trips or are induced trips made possible by the availability of the bicycle

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[1] Central Transportation Planning Staff, Bicycle Traffic Volumes in Metropolitan Boston, Technical Report 37, December 1982, p. 3.

[2] The U. S. Census collected data on travel behavior for the week preceding respondents' completion of the census form, which was due April 1, 1980.

[3] Metropolitan Area Planning Council (MAPC), Minute Man Commuter Bikeway Study, February 1981, p. 45.

mode. The percentage of bicycle trips in the Boston metropolitan area which do not serve as substitutions for automobile trips is likely to be at the upper end of this range, since travel conditions in the region are more like those in Washington, D.C. than they are like those in the state of Pennsylvania as a whole.

Nevertheless, the energy savings associated with major bicycle projects may be in the same range as other potential conservation measures. Projects benefitting other modes are likely to have only marginal effects on the total energy use or savings associated with these modes. Bicycle projects, however, have the potential to produce a sizable increase in bicycle usage and associated energy savings, on a percentage basis. In short, most conservation-oriented transportation projects will produce impacts which are quite small relative to total energy consumption. It is on a cumulative basis that these projects have the potential to yield substantial savings, and bicycle programs can play a small but significant role in a comprehensive energy-conservation strategy.

There are several categories of projects which can improve the safety, comfort, convenience, or security of bicycle use, thus increasing the frequency of travel by this mode. These include:

- the construction of bicycle paths or provision of bicycle lanes on highways
- provision of secure bicycle parking facilities
- promotion of employer-based bicycle-commuting programs

Public programs which emphasize bikeways as a means of facilitating bicycle use are often criticized by cyclists who prefer traveling on streets or highways. This opposition is motivated primarily by the concern that cyclists' access to public roadways will be unduly restricted, and also by the poor design of many existing bicycle paths. However, properly designed bikeways can alleviate some of the major impediments to bicycle transportation and promote more widespread use of bicycles as a transportation mode.

Bicycle Projects in the Boston Area

There are a number of Boston-area bicycle projects currently in the construction, planning, or proposal stage. Phase V of the Dr. Paul Dudley White Bike Path, extending 10.4 miles from Boston through Cambridge and Newton to Watertown Square, has recently been completed, as has a new bicycle path in Wayland. A proposed bikeway in the Braintree/Weymouth area awaits construction, and designs are underway for bikeways in the towns of Winchester, Saugus, Topsfield, and Wellesley.[1]

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[1]Central Transportation Planning Staff, Transportation Element of the State Implementation Plan for the Boston Region, February 1983, p. 48.

Probably the most ambitious potential bicycle project is the proposed Minute Man Bikeway, which would be built along the eleven-mile railroad right-of-way from Bedford Center to the Alewife MBTA station. This project is still under study.

The MBTA has been involved in the development of bicycle-parking facilities, which addresses another important need related to increasing the use of bicycles. Bicycle-parking facilities were provided at Braintree Station and are planned for the Red Line Northwest extension and the Southwest Corridor project. MAPC has identified over 80 additional stations where the improvement or installation of bicycle-storage facilities would serve as an incentive to bicycle travel.[1]

The MAPC is currently developing a program aimed at encouraging employer support of bicycle commuting. In support of this program, MAPC is distributing a brochure to area employers, and plans to sponsor clinics through these employers which will present information useful to potential cyclists.

Energy Impacts

Estimating the effects of public programs on bicycle-traffic volumes is highly speculative. Unlike most of the other actions reviewed in this report, bicycle programs are usually oriented to address such concerns as safety and security, which cannot readily be quantified. The EPA's Bicycle and Air Quality Information Document states, "Bicycle measures should be viewed as demonstration measures, whose effects are expected to be generally positive, but whose magnitude of impact is still unknown."[2]

In 1981 the MAPC issued a study of the proposed Minute Man Bikeway, which included an analysis of potential energy impacts. Acknowledging the tremendous degree of uncertainty associated with their analysis, the authors of this document nevertheless attempted to estimate the impacts of the bikeway project on auto VMT and gasoline consumption. Based on the assumption that the new facility would increase bicycle volumes in the corridor to six times current levels, the report forecasts a reduction of 5,222,270 VMT and 255,000 gallons of gasoline for the year 1987.[3]

The above estimates reflect increases in weekend recreational travel, as well as commuter travel. Since recreational bicycle trips are less likely than commuter trips to represent actual diversions from automobile travel, it may be more accurate to

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[1]Ibid., p. 54.
[2]MAPC, Minute Man Bikeway Study, p. 33.
[3]MAPC, Minute Man Bikeway Study.

exclude recreational trips from energy-impact estimates. Based on the report's assumed sixfold increase in weekday travel only, a reduction of 3.0 million VMT and 148,000 gallons are forecast for the year 1985. Even after the exclusion of recreational trips, these estimates should probably be regarded as optimistic. The assumed increase in bicycle ridership, calculated on a daily basis, exceeds U. S. Census estimates of the total number of (off-season) bicycle commuters in the Boston SMSA. The above figures also do not account for the energy requirements associated with construction of the bikeway facility.

However, this analysis does suggest that the potential energy impacts of large-scale bicycle projects may compare in magnitude to those of other conservation measures. If projects like the Minute Man Bikeway can in fact produce an increase in bicycle ridership equivalent to several times current volumes, resulting reductions in auto VMT and energy consumption may be substantial.

8.0 ADDITIONAL MEASURES

The measures included in this section--shared-ride taxi, transportation pricing, substitution of communications for transportation, traffic restrictions--have frequently been mentioned as potential energy-conservation strategies. However, these actions do not appear to warrant serious consideration as elements in a regional conservation plan, since each suffers from one or more of the following drawbacks:

- anticipated energy impacts associated with the action are actually minimal, or negative
- under conditions of relatively stable prices and supply, the action is politically or institutionally infeasible
- the public sector, particularly at the local and state levels of government, has minimal influence over the implementation of the action

The specific reasons for judging individual measures to be of negligible value are discussed below.

8.1 Shared-Ride Taxi

Shared-ride-taxi services allow more than one passenger or group of passengers to use a taxi at once. There has been a great deal of interest over the last decade in the use of shared-ride taxis and similar types of paratransit services as a public transportation mode in low-density areas. The evidence from a number of these operations indicates that so-called "dial-a-ride" services tend to increase areawide energy consumption. This is due to two factors:

- A relatively large share of dial-a-ride trips are diverted from walk and transit modes.
- Dial-a-ride trips often consume more fuel than the automobile trips they replace, due to the high degree of circuity associated with passenger pick-ups and a low occupancy rate.

While the use of shared-ride-taxi services as a replacement for automobile travel may be generally counterproductive from the standpoint of energy conservation, the effects of substituting shared-ride taxi for traditional taxi services may be more promising. Essentially, the difference in this case would be that the restrictions governing taxi operations would be relaxed for the primary purpose of serving an existing market for taxi serv-

ices more efficiently, rather than expanding that market. In practice, however, reduced-cost taxi services do divert passengers away from other modes, including transit. Lack of support from the taxi industry is also often a major obstacle to implementation of these programs.

A demonstration-shared-ride taxi program, "Share and Save Taxi," is currently in effect in the Allston-Brighton section of Boston. While there is virtually no data currently available on the impacts of this service, the scale of the operation is very small (the vehicle fleet consists of only one taxicab). Any energy impacts associated with the demonstration itself will be minuscule.

Boston regulations currently allow fleet operators to apply for permission to provide shared-ride services, although there have been no cases to date in which this option has been exercised. Widespread adoption of the shared-ride mode of operation thus appears unlikely at the present time. Since the energy impacts of areawide shared-ride operations are uncertain, and possibly negative, it does not appear worthwhile to aggressively promote this type of service as an energy-conservation measure.

Logan Airport services are a possible exception to the above recommendations, for the following reasons:

- Some shared-ride taxi trips may replace trips in which an airline passenger is dropped off or picked up by an auto driver who is not using the airport; passenger drop-offs and pick-ups can be highly wasteful of energy.

- All airport trips have at least one centralized trip end, which facilitates efficient ridesharing.

The number of passengers using Massport's shared-ride-taxi service has declined dramatically in recent years, as a result of deficient marketing and staffing. Improvement and expansion of the current program could result in energy savings, although the magnitude of potential savings depends on a number of factors, such as the modal alternatives from which ridership would be diverted, as well as occupancy rates. Experience indicates that empty "back hauls" are common on this service.

8.2 Pricing Measures

Transportation-pricing measures may entail either the lowering of charges for use of transit and other high-occupancy modes, or the increasing of costs related to automobile travel. Since transit-fare reductions were addressed in section 4.4, this discussion focuses on the latter category of measures.

The principal means by which the cost of driving can be increased are as follows:[1]

- bridge and highway tolls
- congestion tolls
- parking charges
- gasoline tax
- vehicle registration fee or excise tax
- differential registration fee to promote fuel-efficient vehicles

When applied as a disincentive to driving, most pricing measures are certain to incite widespread public opposition. During periods such as the present, when there is not an immediate shortage of energy supplies, the public is not likely to perceive the need for energy-consumption penalties on individual automobile drivers. Paradoxically, at times when energy shortages are more severe, market prices for gasoline rise, alleviating much or all of the need for public pricing disincentives. In short, it appears that as a practical matter, pricing measures to discourage automobile use are unlikely to play a major role in energy conservation, at least at the state or local level. There is probably a greater potential at the national level for building the political consensus required to support these types of actions. While off-street parking surcharges are presently under consideration in the City of Boston, these are intended solely to raise revenues, although reduced auto use may be considered a favorable by-product of the proposal.

Political realities aside, it is clear that properly designed price disincentives would result in a relatively large reduction in VMT-related energy consumption. The MAPC estimated in 1980 that a $.80/gallon increase over the base gasoline price of $1.20/ gallon would yield an energy savings of 8.4 million gallons per year.[2] (This increase could be either the effects of a gasoline tax measure or a rise in the market price.)

Although public opposition appears to be a formidable barrier to pricing disincentives, positive pricing incentives to encourage more efficient use of automobiles would be more feasible from a political standpoint. An example of this type of incentive would be the carpool toll-reduction program administered by the Massachusetts Turnpike Authority. However, the

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[1]Alan M. Voorhees and Associates, Inc., Guidelines to Reduce Energy Consumption Through Transportation Actions, prepared for the Urban Mass Transportation Administration, May 1974, pp. 33-38.

[2]Central Transportation Planning Staff, Transportation Element of the State Implementation Plan for the Boston Region, February 1983, Appendix A, p. 25.

potential is negligible for applying this type of program at additional locations in the Boston area.

Another possible pricing incentive would be a reduction in the annual excise tax assessment for fuel-efficient vehicles. Possible drawbacks related to this type of program include the following:

- Excise taxes have been decreased as a result of Proposition 2½, so that a further fee reduction may not act as an effective incentive to purchase fuel-efficient vehicles.

- Revenue losses would be substantial, since small, fuel-efficient vehicles already account for a sizable share of all automobile purchases.

As a result of these possible drawbacks, an auto-excise-tax-incentive program does not appear to be a promising energy-conservation measure.

8.3 Substitution of Communications for Transportation

The revolution in telecommunications currently underway holds out the prospect of a profound change in the way we live and work. Perhaps the most direct manifestation of that change will be the substitution of communications for transportation as the need to centralize interpersonal transactions and other workplace and marketplace functions declines. It is possible to speculate about the extent to which this type of change may affect the future use of transportation services and consumption of energy. In terms of the relevance of these potential developments to the preparation of an energy-conservation plan, the following points should be noted:

- Large-scale impacts on transportation behavior are unlikely to materialize within a five-to-ten-year time horizon.

- The influence of state and local governments on the nature or rate of potential change is negligible.

For these reasons, public intervention in this area appears unwarranted.

8.4 Vehicle Restrictions

The following actions have been proposed at various times as possible energy-conservation measures:

- restrictions on the use of vehicles by time of day or day of week

- fee charges for the use of vehicles in congested areas

- vehicle-ownership restrictions; i.e., limiting the number of vehicles which can be registered within a given geographical area or to an individual or household

- road-user surcharges for vehicles entering designated areas

- auto restricted zones; i.e., the prohibition of automobiles from designated areas

Only the last of the actions listed above has ever been implemented in the United States, and this on a very limited basis. There are no examples in this country of auto restricted zones which have encompassed more than a few city blocks. Moreover, the numerous ARZs which have been created over the past decade have been, almost without exception, oriented toward achieving a broad range of urban-revitalization goals, rather than energy conservation. The limited evidence available about Boston's Downtown Crossing suggests that the energy impacts associated with this project have been negligible.

Larger-scale ARZs, which might conceivably have significant energy impacts, would meet with tremendous public resistance. In fact, public reaction to all of the vehicle-restriction measures identified in this section would be extremely adverse. Unless there are other objectives (e.g., pollution control or urban revitalization) which justify such unprecedented controls on the use of automobiles, these measures cannot be regarded as viable elements in a public energy-conservation program.

9.0 SUMMARY AND CONCLUSIONS

9.1 Program Costs

Previous sections of this report have focused narrowly on the magnitude of potential energy impacts associated with individual transportation projects. A more complete evaluation of potential energy-conservation measures requires that a number of additional criteria be considered, chief among these being costs.

Table 9-1 summarizes cost estimates, which have been developed for most of the projects included in this report. These estimates, which have been derived from a variety of formal and informal sources, are intended to provide a rough indication of the relative cost-effectiveness of different measures. Costs represented in the table have been confined to project or program costs, which include only those expenses incurred directly in constructing, operating, or administering a project. In most cases, these are the costs incurred by federal, state, and local governments.

Omitted from these estimates are changes in transportation costs for the users of transportation services. Transit revenues, for example, are treated as a reduction in net operating costs, and the estimates do not account for the money which individuals may save as a result of switching from auto to transit or ridesharing. Similarly, there is no consideration of the value of the travel time that may be saved by users of the prospective services. The estimates in the table thus represent only one category of costs, and one limited measure of cost-effectiveness.

The table distinguishes between capital and operating costs, and also provides estimates of annualized total costs, which is the sum of annual operating costs and annualized capital costs. Total annualized costs are divided by projected energy savings, measured in gallons of gasoline, for each project, yielding costs per gallon. As shown in the table, there is a tremendous variation in both capital and operating costs among the different projects, which is not surprising, given the projects' vast disparities in scale.

It is also apparent that the projects differ greatly in terms of cost per gallon saved. The projects with the lowest ratio of costs to energy savings include several of the concurrent-flow high-occupancy-vehicle lanes, ridesharing programs, and variable-work-hours promotion. This is due primarily to the low capital costs entailed in these projects and

TABLE 9-1(a)

Comparison of Program Costs for Potential Energy-Conservation Measures

Project	Capital Cost (dollars)	Annual Operating Cost (dollars)	Annualized Total Cost (dollars)	Cost/Gallon Saved (dollars)
Preferential Treatment for High-Occupancy Vehicles:				
• Extension I-93 Preferential Lane	$2,500-7,000	negligible	$250-1,000	$.15-.27
• Southeast Expressway				
- Northbound Contraflow Lane (AM)	230,000	$150,000-175,000	173,000-198,000	1.73-3.96
- "Reversible" Contraflow Lane (AM & PM)	460,000	300,000-350,000	346,000-396,000	2.16-4.95
- Ramp Metering (2 ramps)	25,000+	variable	variable	variable
- with Neponset Ramp Priority Bypass	2,000-5,000	negligible	1,000	.05-.11
• Route 3 Exclusive HOV Lane	10-30 million	NA	.7-2 million[1]	1.00-2.90
• Route 1A: Reserved HOV Lane	25,000	negligible	2,500	.03-.04
• Mass Pike: Reserved HOV Lane	25,500	negligible	2,500	.07
• Priority Signal Treatments	10,000-15,000 per intersec. (68 intersec.)	negligible	68,000-102,000	.72-1.05
Measures to Improve Total Vehicular Flow:				
• Intersection-Design Modifications	50,000,-75,000	negligible	negligible	-
• Left-turn Prohibition	negligible	negligible	negligible	
• Protected Left Turn	1,000-2,000 per intersec.	negligible	negligible	-
• One-Way Streets	6,000-60,000 per mile	negligible	negligible	-
• Reversible Flow	10,000-150,000	negligible	-	-
• Coordination, Optimization of Traffic-signal Systems	500-1,000 per intersection	negligible	50-100	.01[4]
• Signal Upgrading	5,000-50,000 per intersec.	negligible	500-5,000	1.2-12.0[4]
• Computerized Signal Control	250,000+	50,000+	75,000+	-
• Freeway Surveillance	80,000-1,500,000	100,000-500,000	90,000-650,000	-

TABLE 9-1(b)

Comparison of Program Costs for Potential Energy-Conservation Measures

Project	Capital Cost (dollars)	Annual Operating Cost (dollars)	Annualized Total Cost (dollars)	Cost/Gallon Saved (dollars)
Transit Fuel-Economy Measures:				
• LRV Regeneration	NA			
• Station De-lamping (20 stations)	Negligible	Negligible	NA	Negligible
• Shared Savings Demonstration with Energy Service Company	Negligible	Negligible	Negligible	Negligible
• Reduced Bus Engine Idling	Negligible	Negligible	Negligible	Negligible
• Use Blended Fuel in Buses	Negligible	Negligible	Negligible	Negligible
• Reduced Escalator Operation	Negligible	Negligible	Negligible	Negligible
• Lights Off Program in Stations	Negligible	Negligible	Negligible	Negligible
• Fuel Management System (Pilot)	Negligible	Negligible	Negligible	Negligible
• Reduced Operation of Rail Car Auxiliary Systems	Negligible	Negligible	Negligible	Negligible
• Discontinue Third-Rail & Track-Switch Heaters	Negligible	Negligible	Negligible	Negligible
• Discontinue Express-Track-Platform Operation, Orange Line	Negligible	Negligible	Negligible	Negligible
• Replace Defective Steam Traps Systemwide	Negligible	Negligible	Negligible	Negligible
• Convert Everett Boilers to Use #4 Oil	NA	Negligible	Negligible	Negligible
• Boiler Fuel Preheater Demonstration	Negligible	Negligible	Negligible	Negligible
• Test & Evaluate Sylvania Energy-Efficient Lamps	NA	Negligible	Negligible	Negligible
• Fuel Recovery BET	NA	Negligible	Negligible	Negligible
• Install Dead-band Temperature Controls on Orange & Blue Line Cars	NA	Negligible	Negligible	Negligible
• Install Automatic Lighting Controls for Subway-tunnel Lighting	NA	Negligible	Negligible	Negligible
• Install Automatic Lighting Controls Systemwide	NA	Negligible	Negligible	Negligible
• Install Vandal-resistant, Fixed-point Thermostats Systemwide	NA	Negligible	Negligible	Negligible
• Install Automatic Valve Controls on Radiators	NA	Negligible	Negligible	Negligible

TABLE 9-1(c)

Comparison of Program Costs for Potential Energy-Conservation Measures

Project	Capital Cost (dollars)	Annual Operating Cost (dollars)	Annualized Total Cost (dollars)	Cost/Gallon Saved (dollars)
Transit Fuel-Economy Measures (cont'd):				
• Install Automatic Pressure-Control Valves on Steam Lines at Cabot	NA	Negligible	Negligible	Negligible
• Install Automatic Layover Controls on Rail Cars	NA	Negligible	Negligible	Negligible
• Modernize D.C. Lighting System (Part of Station Modernization)	NA	Negligible	Negligible	Negligible
• Improve Power Transmission & Distribution System	NA	Negligible	NA	NA
Major New Transit Services:				
• Red Line Northwest Extension to Arlington Heights	1 billion[2]	NA[3]	28.6 million[1]	64.00[1]
• North Shore Transit Improvements				
- Blue Line Extension to Lynn	224.788 million[5]	2.2 million[6]	21.5 million	-
- Commuter Rail Upgrade	143.0 million[5]	503,700[6]	11.8 million	29.50
- Wonderland Station Upgrade	65.5 million[5]	208,800[6]	5.8 million	226.90
• Roxbury-South End Replacement Project	NA	NA	NA	NA
• Forest-Hills-to-Needham Service	11.6-30.2 million (1976)	1.3-2.5 million (1975)	NA	-
• Orange Line Extension: Oak Grove North to Route 128	NA	NA	NA	NA
• Green Line Extension to Tufts	40-85 million (1981)	NA	1.6-3.4 million[1]	NA
• Rail Service to Brockton	NA	NA	NA	NA
Expansion of Bus Routes:				
• Boston-North Shore Office Parks	NA	105,000-357,000	105,000-357,000[7]	8.00-35.7
• Kendall Square Crosstown	NA	NA	NA	NA

TABLE 9-1(d)

Comparison of Program Costs for Potential Energy-Conservation Measures

Project	Capital Cost (dollars)	Annual Operating Cost (dollars)	Annualized Total Cost (dollars)	Cost/Gallon Saved (dollars)
Increase Schedule Frequency:				
• Reduce Bus Headways by One-Half (systemwide)	200 million	56 million[6]	76 million[7]	-
Fare Reductions:				
• Eliminate Fees at 450 Commuter Parking Spaces	-	30,000	30,000	1.00
Commuter Parking Spaces:				
• MBTA Transit Park-Ride Improvement Program (4100 spaces)	11.9 million	NA	1.2 million[1]	1.95
• Additional 900 Surface Commuter Parking Spaces	1.5 million	NA	150,000[1]	1.35
Ridesharing:				
• Caravan Vanpool Program - Estimated 1985	NA	2,500,000[8]	2,500,000[8]	.10
• Carpool Matching and Promotion	-	25,000-100,000	25,000-100,000	.07-.14
Variable Work Hours:				
• Promotion	-	25,000-100,000	25,000-100,000	.04-.15
Compressed Work Week:				
• Promotion	-	100,000+	100,000+	.28-.56

TABLE 9-1(e)

Comparison of Program Costs for Potential Energy-Conservation Measures

Project	Capital Cost (dollars)	Annual Operating Cost (dollars)	Annualized Total Cost (dollars)	Cost/Gallon Saved (dollars)
Bicycling				
• Promotion	-	10,000-50,000	10,000-50,000	-
• Minute Man Commuter Bikeway	1,500,000-2,000,000	26,000	175,000-226,000	1.20-1.50

NA = Not Available.

- = Not Applicable.

[1]Capital cost only.

[2]Estimate from 1977 Red Line extension EIS, inflation adjusted.

[3]Operating costs associated with Red Line extension will be partially offset by reduced bus operating costs.

[4]Long-term energy impacts uncertain. Value shown represents maximum short-term benefit; i.e., lowest possible cost per gallon saved.

[5]1981 dollars; cost estimate from Draft Environmental Impact Statement, North Shore Transit Improvements Project.

[6]Net operating cost (i.e., cost-revenue).

[7]Operating cost only.

[8]Vanpool operating costs include van leasing. Approximately 90% of cost paid by users.

programs. It should be noted that the estimated energy savings associated with variable-work-hours programs is quite speculative, as is the projected ratio of costs to energy savings. Also, as has been discussed previously, estimates of energy savings for ridesharing programs are likely to be optimistic. This is particularly true of vanpooling, since a large share of the potential vanpool market is already participating in the area's vanpool program.

The projects with the highest ratio of costs to energy savings are the rapid-rail extensions, due to their high capital costs. This is not surprising, given the large scale of these projects. Major transportation projects such as these can be expected to produce impacts which are significantly broader in scope and greater in magnitude than those associated with smaller, TSM-type projects. Such considerations as user travel-time and cost savings, as well as regional traffic conditions, thus take on greater importance in the case of larger-scale projects. Energy conservation represents only one of the multiple benefits which may result from these projects, and a narrow focus on energy impacts is inadequate to represent the project's value. In addition, in the case of the Red Line Northwest extension, estimated energy savings are based on ridership levels forecast for the year 1980, and do not therefore reflect future ridership growth. As a result, it is likely that energy savings would be substantially greater than those estimated here over the life of the project, and the cost per gallon of gasoline saved would be significantly lower.

9.2 Summary and Evaluation of Measures

This section presents a comparison of the measures analyzed on an individual basis earlier in this report. Net energy savings and program costs have been considered in previous sections. The results of these analyses are presented here in summary form, along with an assessment of the measures in terms of the following criteria:

- mobility and travel time - impacts on traffic conditions and the quality of transportation services in the region
- economic and institutional feasibility - likelihood of implementation, taking into account both economic and institutional constraints

The comparison is summarized in Table 9-2.

Projects with Substantial Conservation Potential

The projects and programs which are estimated to result in relatively large energy savings of 400,000 or more gallons annually are as follows:

Project or Program	Annual Energy Savings (in gallons of gasoline)
• Route 3 Exclusive HOV Lane	650,000
• Red Line Extension to Arlington Heights	450,000
• North Shore Commuter Rail Upgrade	400,000
• MBTA Transit Park-Ride Improvement Program	615,000
• Transit Fuel Economy Measures	1,500,000
• Caravan Vanpool Improvement Program	2,500,000
• Carpool Matching and Promotion	1,500,000
• Variable Work Hours	670,000
• Compressed Work Week	480,000-960,000

The cost-effectiveness of these programs, as measured by the ratio of program cost to energy savings, was reported in the previous section. As noted in that discussion, the program costs for several of the above measures are quite high in relation to potential energy savings. Projects whose costs exceed $20 per gallon of savings include the Red Line Northwest Extension and North Shore Commuter Rail Upgrade. Both of these projects, however, rate higher than any others in terms of their expected impacts on mobility and travel time within the Boston region.

While several of the measures, such as ridesharing and variable-work-hours promotion, may result in greater net energy savings, these latter programs offer little in the way of travel-time savings or increased convenience, and will benefit only a narrow market; i.e., certain categories of commuters. In contrast, the transit projects would serve a broader market and would offer an increase in level of service, as well as reduced travel costs in many cases, to those who use the new services. None of the other measures analyzed in this report can provide equivalent benefits in terms of both energy savings and level of service.

One of the transit projects identified above does not fare well, however, in terms of economic/institutional feasibility, at least in the short term. Since the federal government is not presently funding new rapid-rail extensions, the segment of the Red Line extension from Alewife to Arlington Center (or beyond)

will not be built in the near future. Public opposition at the local level poses another potential obstacle to the project. Transit fuel-economy measures, on the other hand, which range from new bus-driving procedures to electric power transmission and distribution improvements, tend to be quite cost-effective and relatively non-controversial from a political and institutional perspective.

Projects with Moderate Conservation Potential

Additional projects which may be beneficial from the standpoint of energy conservation are as follows:

- Southeast Expressway Contraflow Lane
- Route 1A: Reserved HOV Lane
- Priority Signal Treatments
- Roxbury-South End Replacement Project
- Orange Line Extension - Oak Grove North to Route 128
- Upgrading, Maintenance, and Rehabilitation of Transit Equipment and Facilities
- Increase in Number of Commuter Parking Spaces
- Bikeways

Projected annual energy savings for most of the above projects range from fifty thousand to several hundred thousand gallons. While energy impacts have not been quantified for the transit projects in this group, it is likely that annual savings for these would also be in this range, although in the case of the Orange Line extension energy impacts may be somewhat greater in magnitude. All of the above projects would have beneficial impacts on mobility and travel time, except perhaps the Route 1A Reserved HOV Lane. The effect of this project on travel conditions would depend on its feasibility from the standpoint of traffic flow. This is an area which requires additional study.

Most of the projects in this group are rated high in terms of economic and institutional feasibility. In fact, plans for the reconstruction of the Southeast Expressway already include a northbound contraflow lane. The only project which does not appear promising from the perspective of financial or institutional feasibility is the Minute Man Bikeway. It does not appear likely that the Minute Man Bikeway will be implemented, because it would occupy the same right of way as an extension of the Red Line beyond Alewife Station, which remains a long-term possibility.

Projects with Negligible Potential

There are several projects included in the table which are likely to result in negligible energy savings or possibly even some increase in energy consumption. They are listed below:

- Extension of I-93 Preferential Lane
- Southeast Expressway Neponset Ramp Priority Bypass (in conjunction with ramp metering)
- Massachusetts Turnpike: Reserved HOV Lane
- Traffic-Flow-Improvement Measures
- Blue Line Extension to Lynn
- Wonderland Station Upgrade
- Green Line Extension to Tufts
- Rail Service to Brockton
- New Bus Routes: Boston-North Shore Office Parks, Kendall Square Crosstown
- Elimination of Parking Fees at Commuter Rail Stations
- 50% System-wide Reduction in Bus Headways

The majority of these projects are estimated to produce positive impacts of small magnitude. These projects may be justified on grounds other than energy conservation. In some cases, implementation costs are so low that the projects are highly cost-effective in terms of money expended per gallon of energy saved, although total energy savings are small. For example, while an extension of the I-93 Preferential Lane would result in only a small reduction in total energy consumption, this could be achieved at the low public cost of 15 to 27 cents per gallon saved. The project would also have beneficial travel-time impacts. Therefore, projects in this category should not necessarily be dismissed, although their energy-conservation impacts are likely to be minimal.

Traffic-flow-improvement measures, which may range from signal optimization to freeway surveillance and ramp metering, were judged earlier in this report to have little value as energy-conservation techniques. This conclusion is based on research which indicates that improved highway travel conditions may produce short-term energy savings, but in the longer run will result in increased energy consumption, due to more frequent use of automobiles.

Recommendations

There are several projects and programs which merit a strong endorsement as energy-conservation measures. These are projects which are estimated to produce relatively large energy savings at low public cost, and which will produce beneficial impacts on local or regional travel conditions. They are as follows:

- Route 3 Exclusive HOV Lane
- Transit System Fuel-Economy Measures
- Increase in Number of Commuter Parking Spaces
- Caravan Vanpool Program
- Carpool Matching and Promotion
- Variable-Work-Hours/Compressed-Work-Week Programs

The Caravan program appears to be functioning well and probably does not require special support as part of a public conservation effort. The remaining projects and programs probably do require additional investments of resources and attention.

There are serious questions concerning the feasibility of one of these programs: the Route 3 Exclusive HOV Lane. The merit of this project depends on the quality of traffic flow entering the Southeast Expressway from the HOV lane. Since plans for the reconstructed expressway do not include provisions for a Route 3 HOV lane, it may not be possible to provide suitable connections from the lane to the expressway.

Institutional feasibility is a possible concern in the case of variable-work-hours/compressed-work-week programs. This is particularly true for compressed-work-week promotion. It is clear that these programs can produce substantial energy savings, and estimated savings presented in this report are based on assumed participation rates which can be considered conservative. These participation rates are nevertheless quite speculative. The extent to which a publicly sponsored promotional effort can influence participation rates in an employer-based program is particularly unclear, especially during periods when energy prices are stable and conservation is not broadly viewed as a matter of great urgency. The level of energy savings estimated in this report for these programs is more likely to be attained under conditions of increasing fuel prices. However, since the cost of public promotional efforts in these areas is modest, the programs will prove to be cost-effective even if actual energy savings are substantially lower than the estimates presented here.

A similar case can be made for ridesharing programs. While there is evidence that the energy savings associated with carpooling and vanpooling may be substantially less than is generally believed, public programs in this area would be beneficial and cost-effective if only a fraction of estimated savings were achieved.

Total estimated energy savings for all of these recommended programs combined is 8.0 to 8.5 million gallons per year; this is approximately one percent of baseline regional energy consumption in the transportation sector. The estimated annual cost for these projects and programs is in the range of five-to-six million dollars, which yields a cost per gallon saved of $.60-.75.

There are also a number of projects which would be beneficial in terms of their energy and transportation impacts, but which cannot be recommended for implementation at the present time on the basis of their conservation potential alone. These projects are estimated to produce a lower level of energy savings than the projects and programs previously recommended, or are considerably more expensive (particularly in terms of cost per gallon of savings). Projects in this category may merit consideration on the basis of their broader impacts on mobility and travel times, in addition to their energy-conservation potential. The projects are:

- Red Line Extension to Arlington Heights
- North Shore Commuter Rail Upgrade
- Southeast Expressway Contraflow Lane
- Route 1A: Reserved HOV Lane
- Priority Signal Treatments
- Roxbury-South End Replacement Project
- Orange Line Extension - Oak Grove North to Route 128
- Upgrading, Maintenance and Rehabilitation of Transit Equipment and Facilities
- Bikeways

Quantitative estimates of energy impacts are not available for several of the above measures. The estimated annual energy savings for the remainder of these measures combined is one or two million gallons, a small amount compared to the savings associated with the recommended projects. Estimated total savings for both recommended projects and those included in this second group are nine to ten million gallons per year. This level of savings can be regarded as the maximum potential impact of Boston-area public conservation efforts in the transportation sector, assuming that energy supplies remain relatively stable and that prices do not rise precipitously.

9.3 Project Review and Program Monitoring

It has been the intention of this report to be reasonably comprehensive in identifying potential energy-conservation projects. The set of projects and programs which has been considered is not exhaustive, however, and there inevitably remains a wide spectrum of additional potential projects which could conceivably affect regional energy consumption. Energy conservation is likely to persist as a public policy concern over the next decade, and it is impossible to address the continuing needs in this area with a single report or set of projects.

It is fundamental to continuing conservation efforts that an adequate mechanism be established for coordinating the collection of information on energy-consumption levels and relevant projects. This function can be broken down into several tasks:

- monitoring of progress on projects and programs recommended in this report
- review and analysis of additional projects which may affect energy consumption
- monitoring of regional energy consumption levels

These three tasks may be considered the proposed scope of further work by CTPS in the area of energy conservation. Each of the tasks is described below.

Monitoring of Progress on Recommended Projects

It is the responsibility of the MPO to evaluate and respond to the recommendations in this report. In the event that the MPO does decide to support one or more of the recommended projects, it is proposed that CTPS collect information on the project's development and progress toward implementation. CTPS would also be available at the request of the SSC to provide technical assistance in the design or evaluation of recommended programs.

Review and Analysis of New Projects

The MPO is certain to undertake new projects and programs over the next few years which have not been evaluated as part of this report. The same straightforward methods used in this report to estimate energy consumption impacts can be applied to analyze additional projects as they are proposed. This analysis may then be considered in the overall evaluation of a proposed project. At a minimum, the analysis results would serve to update the MPO's knowledge of regional energy consumption and conservation.

Monitoring of Regional Consumption Levels

This task would consist of updating the information on regional energy consumption presented in chapter 1.0 of this report. The information to be assembled will document changes in transportation-related energy consumption in the Boston region. The specific indicators which would serve as the basis for this continuing monitoring function are as follows:

- annual vehicle-miles of travel in the communities which constitute the Boston region
- statewide vehicle-fleet fuel consumption
- fuel consumption related to MBTA operations

This information, evaluated in combination with estimates of project-related conservation impacts, should provide a strong indication of the effectiveness of public energy-conservation efforts.

TABLE 9-2(a)

Comparison of Measures

Project	Total Annual Energy Savings (gallons)	Costs Per Gallon (dollars)	Mobility/ Travel Time	Economic/ Institutional Feasibility
Preferential Treatment for High-Occupancy Vehicles:				
• Extension I-93 Preferential Lane	3,600-8,000	.15-.27	+	+
• Southeast Expressway				
- Northbound Contraflow Lane (AM)	50,000-100,000	3.50-4.00	+	++
- "Reversible" Contraflow Lane (AM & PM)	80,000-160,000	4.30-5.00	+	-
- Ramp Metering (2 ramps)	+	NA	+	-
- with Neponset Ramp Priority Bypass	10,000-22,000	.05-.11	+	-
• Route 3 Exclusive HOV Lane	650,000	1.00-2.90	+	-
• Route 1A: Reserved HOV Lane	67,500-87,500	.03-.04	+	-
• Mass Pike: Reserved HOV Lane	9,000-37,500	.07	-	-
• Priority Signal Treatments	87,500-100,000	.70-1.05	+	+
Measures to Improve Total Vehicular Flow:				
• Intersection Design Modifications	-	-	+	+
• Left-turn Prohibition	-	-	+	+
• Protected Left Turn	-	-	-	+
• One-Way Streets	-	-	+	variable
• Reversible Flow	-	-	+	variable
• Coordination, Optimization of Traffic-signal Systems	10,000 per intersec.[1]	.01[1]	+	+
• Signal Upgrading	400 per intersec.[1]	1.20-12.00	+	+
• Computerized Signal Control	-	-	++	variable
• Freeway Surveillance	-	-	+	- or +

TABLE 9-2(b)

Comparison of Measures

Project	Total Annual Energy Savings (gallons)	Costs Per Gallon (dollars)	Mobility/ Travel Time	Economic/ Institutional Feasibility
Transit Fuel-Economy Measures:	1.5 million	Negligible	-	+
Major New Transit Services:				
• Red Line Northwest Extension to Arlington Heights	450,000[2]	64.00	++	--
• North Shore Transit Improvements				
- Blue Line Extension to Lynn	-	-	++	--
- Commuter Rail Upgrade	400,000[2]	30.00	++	+
- Wonderland Station Upgrade	26,000[2]	226.90	+	+
• Roxbury-South End Replacement Project	290,000-440,000[3]	NA	+	++
• Forest-Hills-to-Needham Service	-	-	-	+
• Orange Line Extension: Oak Grove North to Route 128	1,025,000[3]	NA	++	--
• Green Line Extension to Tufts	146,000[3]	NA	+	--
• Rail Service to Brockton	117,000[3]	NA	+	-
Expansion of Bus Routes:				
• Boston-North Shore Office Parks	10,000-30,000	8.00-36.00	+	+
• Kendall Square Crosstown	0-25,000	NA	- or +	+
Increase Schedule Frequency:				
• Reduce Bus Headways by One-Half (systemwide)	-	-	++	--

TABLE 9-2(c)

Comparison of Measures

Project	Total Annual Energy Savings (gallons)	Costs Per Gallon (dollars)	Mobility/ Travel Time	Economic/ Institutional Feasibility
Fare Reductions:				
• Eliminate Fees at 450 Commuter Parking Spaces	29,000	1.00	-	+
• Upgrading, Maintenance, and Rehabilitation of Transit Equipment and Facilities	+	NA	++	++
Commuter Parking Spaces:				
• MBTA Transit Park-Ride Improvement Program (4100 spaces)	615,000	2.00	+	++
• Additional 900 Surface Commuter Parking Spaces	110,000	1.35	+	+
Ridesharing:				
• Caravan Vanpool Program (1985)	2,500,000	.10	+	++
• Carpool Matching and Promotion	1,500,000	.07-.14	+	++
Variable Work Hours:				
• Promotion	670,000	.04-.15	+	+
Compressed Work Week:				
• Promotion	480,000-950.000	.28-.56	+	- to +

TABLE 9-2(d)

Comparison of Measures

Project	Total Annual Energy Savings (gallons)	Costs Per Gallon (dollars)	Mobility/ Travel Time	Economic/ Institutional Feasibility
Bicycling				
• Promotion	NA		-	+
• Minute Man Commuter Bikeway	150,000	1.20-1.50	+	--
Shared-Ride Taxi	-	-	-	-
Transportation-Pricing Measures	++	-	-	--
Substitution of Communications for Transportation	++	NA	-	+
Traffic Restrictions	+	NA	-	--

[1]Long-term energy impact uncertain. Value shown represents maximum short-term energy savings.

[2]Net energy savings.

[3]Energy savings related to reduction in auto VMT only; does not account for energy consumed in transit-system construction or operation.

Symbols:

- negligible impact or not applicable
+ positive impact; favorable
++ strong positive impact; highly favorable
NA data not available